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EVALUATION OF THE CANMET/WESTAR PROGRAM FOR SUBSIDENCE MONITORING OVER THICK AND STEEP SEAM MINING

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MICROMEDIA

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SECTION 1

SUMMARY

This evaluation of the Canmet/Westar 8 year program for subsidence monitoring over 15 metre thick and steep (up to 55 degrees) seam coal mining areas at Sparwood, B.C. addresses the effectiveness of the eight years of activity. Mining is by hydraulic jet cutting from sub-level driven by continuous miner near the bottom of the seam. The program included underground covergence measurements, pillar deformation observations, bed separation monitoring and support loading measurements. On the surface, three methods were introduced to measure the ground movement on the steep (+30 degrees) hillside:

- Electronic Distance Measurement (EDM).
- Use of tiltmeters (8 purchases for $250,000 total).
- Aerial Photogrammetry.

The first method proved to be the most effective to provide a quick inexpensive accurate method of measuring surface movement over active mine workings, even during winter months.

This review represents the opinions of Westar which are as follows:

1. The subsidence measurement requirements of the Coal Mines Regulations and Corporate organizations were satisfied.

2. The Canmet final report emphasized the surface aspects, to the partial exclusion of the underground aspects.

3. The project organization as set up should have worked satisfactorily, but due to many changes in staff of both parties, it was tenuous at times, but rallied after the air blast incident in early 1982. Information flow was a little slow at times. Reporting was generally defficient in that problems were not aired and new directions agreed, if necessary.

4. The program was somewhat geared to developing instrumentation in the early stages, but became more practical, and therefore of more interest to the operators about half way through. After the air blast, the importance of establishing that the roof had collapsed became paramount.

5. The quality of measurements is considered sufficiently accurate for the requirements.

6. The techniques developed during the program will be useful for Westar and other mine organizations, especially those planning hydraulic or other methods to extract thick seams.

7. One of the stated objectives was to draw up parameters for underground mine design. It was disappointing that this was not done.

8. Any future work should involve a study of the effect of faulting and the variation in percentage of coal extraction, which was carefully measured.

Section 1

RESUME

Cette évaluation du programme (8 ans) de Canmet / Westar pour la surveillance d'affaissement au-dessus de quinze mètres d'épaisseur avec une pente (plus de 55 degré), pour les couches de charbon de Sparwood en C.B. adresse l'efficacité et l'influence de ces huit années d'activités. L'exploitation minière se fait par coupe à jet hydraulique du niveau inférieur à un niveau continuel près de la base de la couche. Le programme incluait les mesures de convergence souterrainne, les observations sur la déformation des piliers, la surveilllance de la séparation en couche, les mesures de la charge des supports. En surface, trois méthodes étaient introduites pour mesurer le mouvement du sol en pente (+ 30 degré) au flanc de la colline.

* La distance mesurée électroniquement (DME)
* L'emploi d'un inclinateur (l'achat de 8 inclinateurs ayant une valeur totale de $250,000.00)
* La photogrammétrie aérienne

La première méthode était la plus efficace, tout en étant rapide, peu coûteuse et précise. Elle mesurait le mouvement de surface d'une exploitation minière très active, même durant les mois d'hiver.

Cette revue représente les opinions de Westar qui sont les suivantes:

1. Les demandes pour les mesures d'affaissement , les règlements sur les mines de charbon et sur les organismes constitués étaient adéquats.

2. Le rapport final de Canmet appuit fortement les aspects de mines de surface excluant en partie les aspects souterrains.

3. L'organisation du projet, en tant que telle, aurait dû se dérouler d'une façon satisfaisante, mais dû à plusieurs changements du personnel dans les deux groupes, la situation était devenue fastidieuse. Mais l'explosion, au début de 1982,les a rallié à nouveau. L'information de mise à jour était quelquefois un peu lente à nous parvenir. Les comptes rendus étaient généralement pauvres dans le sens que les problèmes n'étaient pas soulevés, puis de nouvelles directives étaient acceptées.

4. Au début du programme, la présentation de l'équipement était plutôt théorique. mais à peu près au milieu, celui-ci devenait plus pratique et sucitait l'intérêt des opérateurs.

Après l'explosion , l'effondrement du toit devenait d'une extrême importance.

5. La qualité des mesures prises était considérée suffissamment exacte pour répondre aux normes.

6. Les techniques développées, durant le programme seront utiles pour Westar et pour les autres organismes miniers, surtout ceux qui considèrent l'utilisation des méthodes hydrauliques ou autres servant à l'extraction des couches épaisses.

7. Un des objectifs cités était d'établir les plans des paramètres pour la planification des mines souterraines. Malheureusement, cela n'a pas été fait.

8. A l'avenir, tout projet devra conduire à une étude sur les effets des failles et leurs variations selon le pourcentage d'extraction du charbon, lequel devrait être minitieusement mesuré.

Le coût total d'exploitation en dépenses réelles pour une période de huit ans était approximativement de $350,000.00 . Il est estimé que Canmet a dépensé une fois et demi à deux fois le montant prévu.

SECTION 2

INTRODUCTION

2.1 General

In preparing this report, the author has drawn on his own knowledge of the program, with considerable help from Brian Hart, now working in Westar Engineering.

Conversations were held with the following people currently in post to check the opinions of the Mining Company.

Lawrence Riffel, General Superintendent
Arist Bruemmer, Director of Mine Planning

In addition, discussions were held with engineers who were in post during the program

Brian Hart, General Superientendant
Boya Kosmak, Manager, Underground Mine Engineering
Rolando Jeria, Supervisor, Mine Planning

2.2 Geological Setting

Westar's mining operations are located in Sparwood, British Columbia. The coal properties comprise the central part of the belt of coal measures that extend for many miles. These coal deposits lie in three basins: The Flathead, Crowsnest and the Upper Elk Valley, and occur in a long structural trough. See Figure 1.

The Kootenay formation, in which Westar is mining, reaches a maximum thickness of 650 meters and contains from 8 to 15 coal seams ranging in thickness from 1.5 to 16 meters.

Coal Mining is primarily carried out in the #10 seam which is 15 meters thick and occurs at the bottom of the Kootenay Formation and is overlain by beds of sandstone, siltstone and shale. The seam is also characterized by steep pitching (10^{0} - 55^{0}) and some major and minor thrust faults. General stratigraphy is shown on Figure 2.

2.3 Mining System

The hydraulic mine was divided into several panels, each of which was extracted progressively. Development work consisted initially of twin main entries extending to the down dip extremity of the panel to be mined (Figure 3). The entries were driven at a rising gradient of about 5^{0} and are contained within the seam. The entry to the rise usually contained the flumes used for hydro-transportation of the coal slurry. During development drivage, this entry was the main intake airway and the lower entry the main return airway. The entries were connected by cross-cuts spaced up to 350m apart. Sub-levels were

driven at an oblique angle to the main entries at a minimum rising gradient of 5^{0}, at about 25m centres and up to 250m long. Future sub-levels however were more than twice this length. The optimum location of sub-levels within the seam is near the footwall.

In the area of the hydraulic mine selected for investigation, the coal seam was normally extracted to a height of about 15m under a cover of approximately 250-300m where the seam dips at about $30\text{-}35^{0}$. Both the main roadways and sub-levels (production headings) were driven by continuous miners and were supported by Toussaient Heinzman piece yielding arches having I-beam girders and flexible arches at the junctions. The arches were set at 1.5m intervals and were lined with 5cm thick wood lagging. The hydraulic monitor starts coal cutting at the upper end and retreats by approximately 12m in one stage. The monitor can swing about 90^{0} horizontally and 90^{0} vertically. The gradient of roadways provides gravity flow of the coal-water slurry out of the mine (Figures 3 and 4).

2.4 Background

Hydraulic underground mining has been successfully carried out in the #10 coal seam since the late sixties initially with a test mine and subsequent mines namely Panel 4, 5 and 6.

In the fall of 1974 surface movement above the mined out area of Panel 4A was discovered in the form of cracks, maximum 5 meters wide and steps appearing at random distances with maximum throws of 0.6 meters. Figure 5.

The surface above Panel 4A is rugged and has a thick cover of bush and trees on a shallow layer of sandy soil; sandstone outcrops in the area form several cliffs up to 16 meters high. Depth of cover varied between 250 meters at the top of the hill to 45 meters at the edge of the outcrop pillar.

In 1974 there was very limited research or information available on general subsidence in Canada. However, in other countries some studies had been performed in steep and thick seam mining. Consequently Westar Mining (Kaiser Resources Ltd. at that time) and Canmet initiated a joint research program to study "Subsidence Monitoring During Working of a Steeply Dipping Coal Seam".

2.5 Program

The main objectives of this 3 year research program were:

a) To understand the principal zones of movement as coal is extracted during the development and production stages of the hydraulic mining operation.

b) To study the surface movement accompanying the extraction of coal.

FIGURE 1

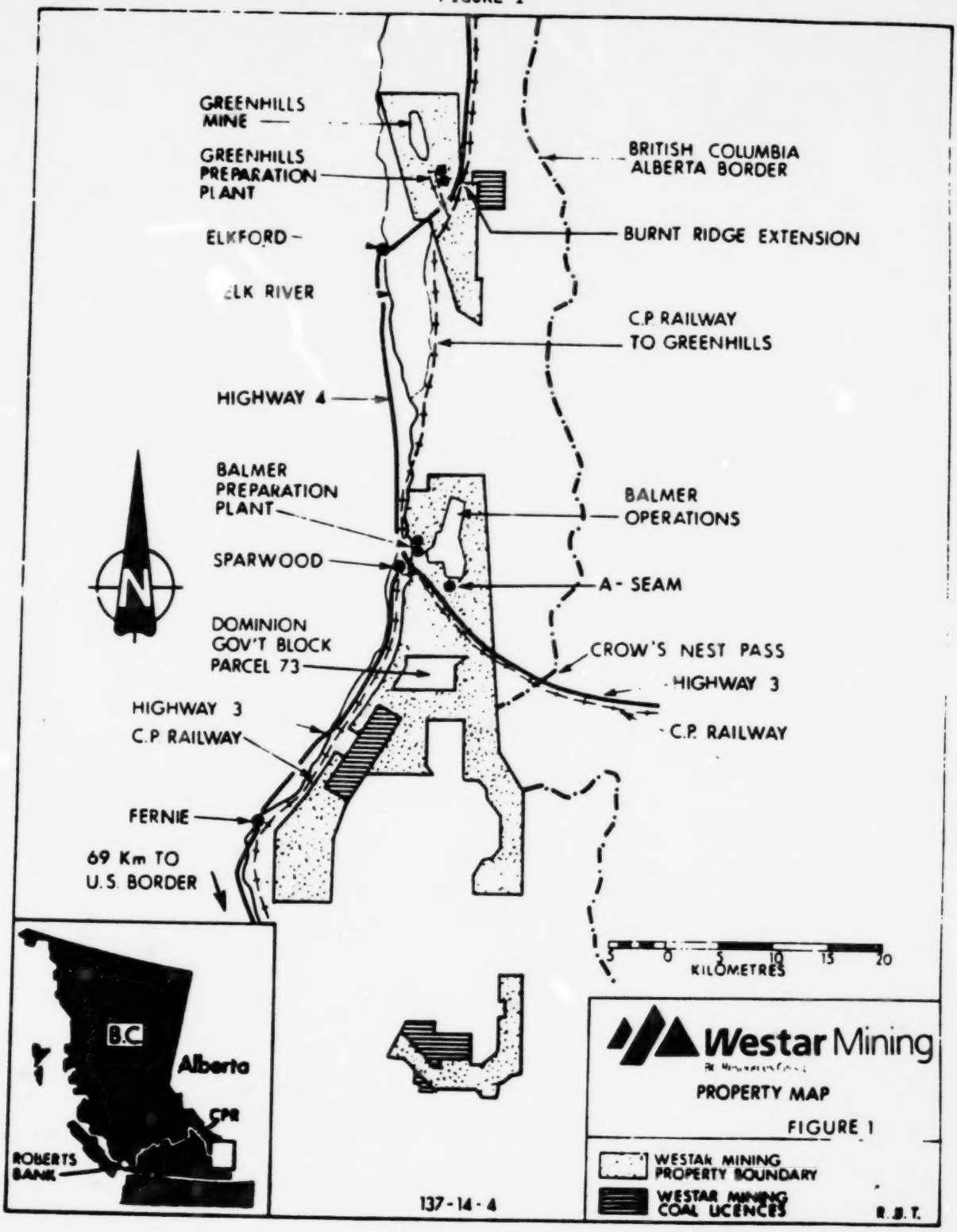

GREENHILLS MINE
GREENHILLS PREPARATION PLANT
ELKFORD
ELK RIVER
HIGHWAY 4
BALMER PREPARATION PLANT
SPARWOOD
DOMINION GOV'T BLOCK PARCEL 73
HIGHWAY 3
C.P. RAILWAY
FERNIE
69 Km TO U.S. BORDER
BRITISH COLUMBIA ALBERTA BORDER
BURNT RIDGE EXTENSION
C.P RAILWAY TO GREENHILLS
BALMER OPERATIONS
A - SEAM
CROW'S NEST PASS
HIGHWAY 3
C.P. RAILWAY
N
5 0 5 10 15 20
KILOMETRES
B.C.
Alberta
CPR
ROBERTS BANK
137-14-4
Westar Mining
PROPERTY MAP
FIGURE 1
WESTAR MINING PROPERTY BOUNDARY
WESTAR MINING COAL LICENCES
R.J.T.

FIGURE 2
IMMEDIATE STRATA ABOVE UNDERGROUND WORKINGS
(No. 5 Sub-level)

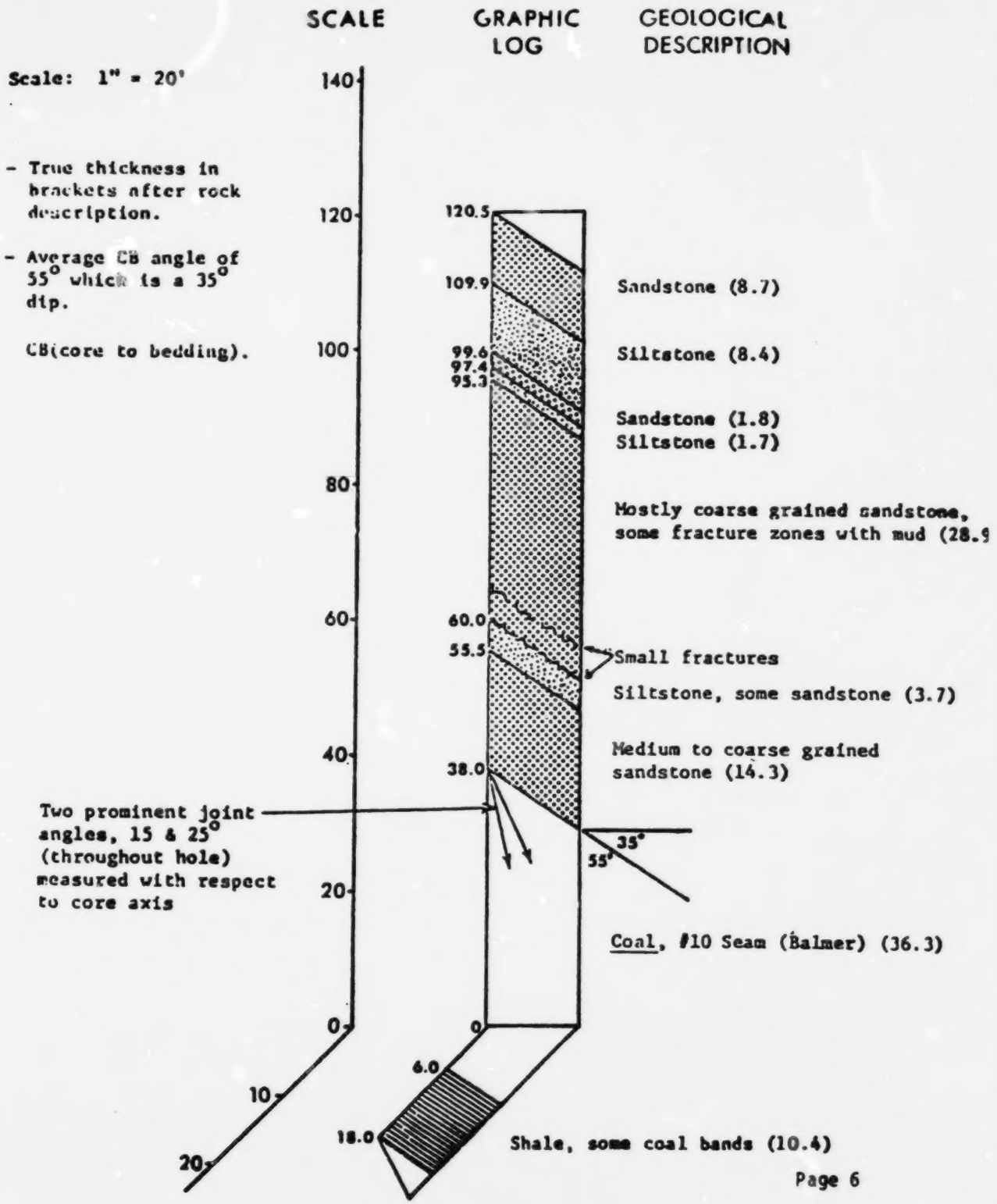


FIGURE 3

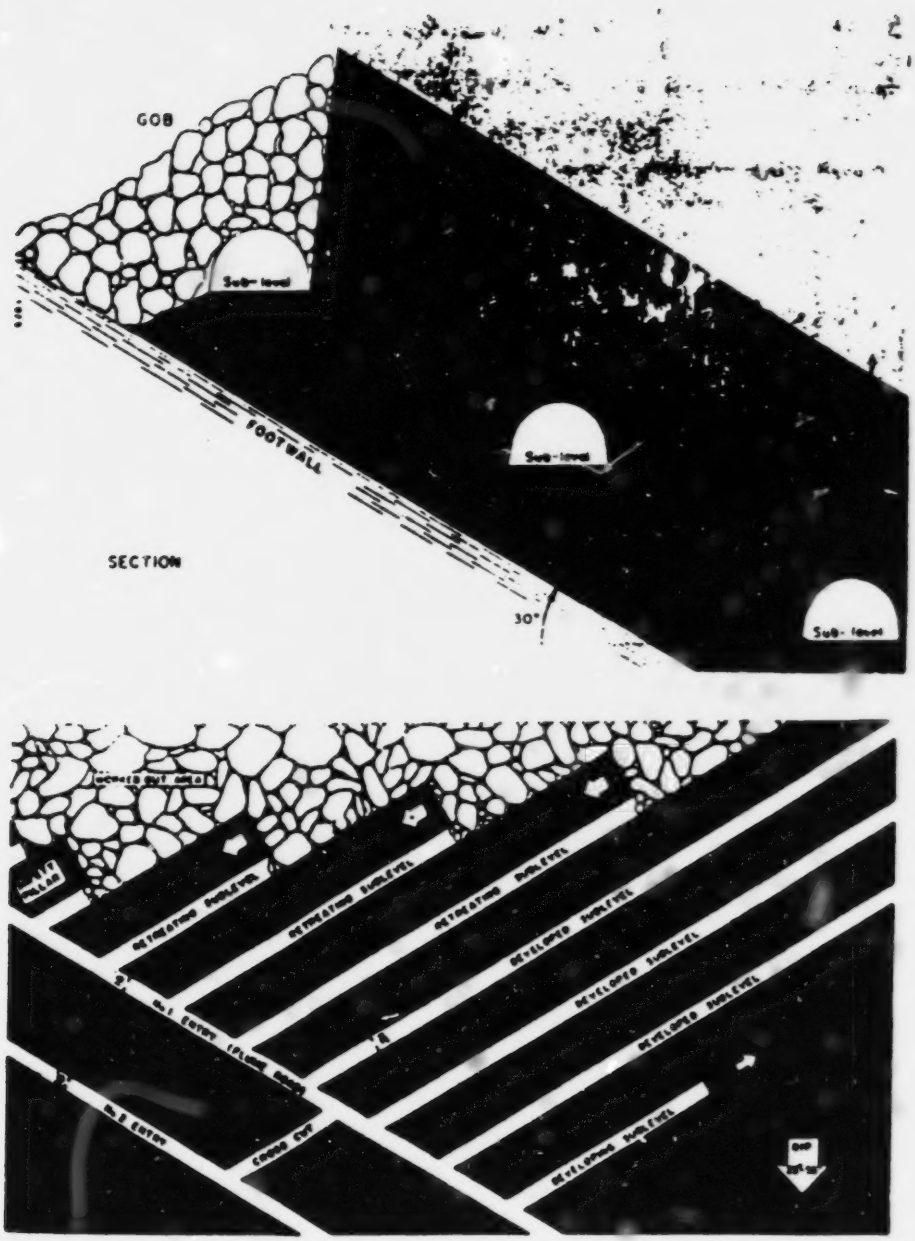
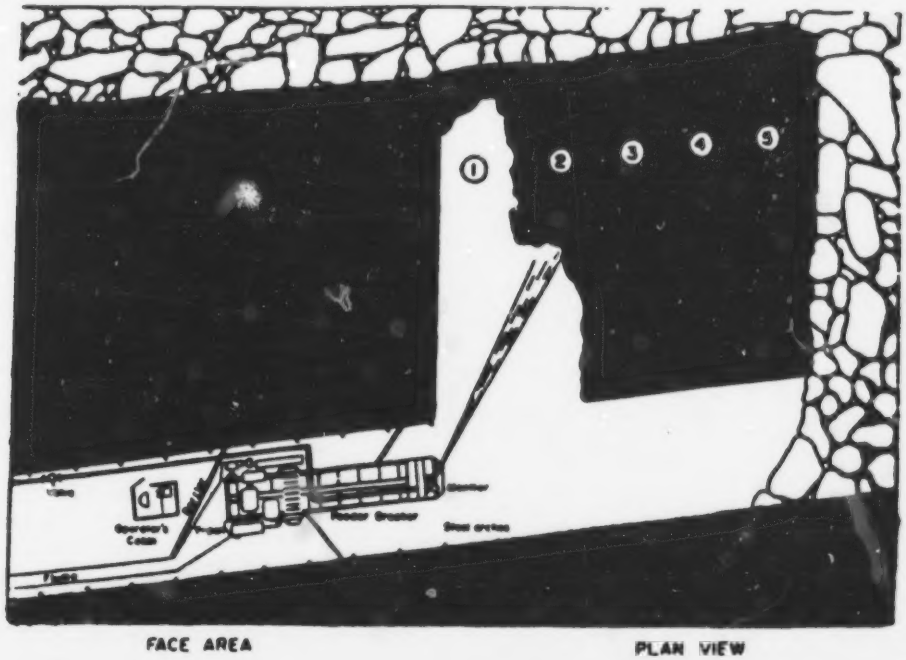
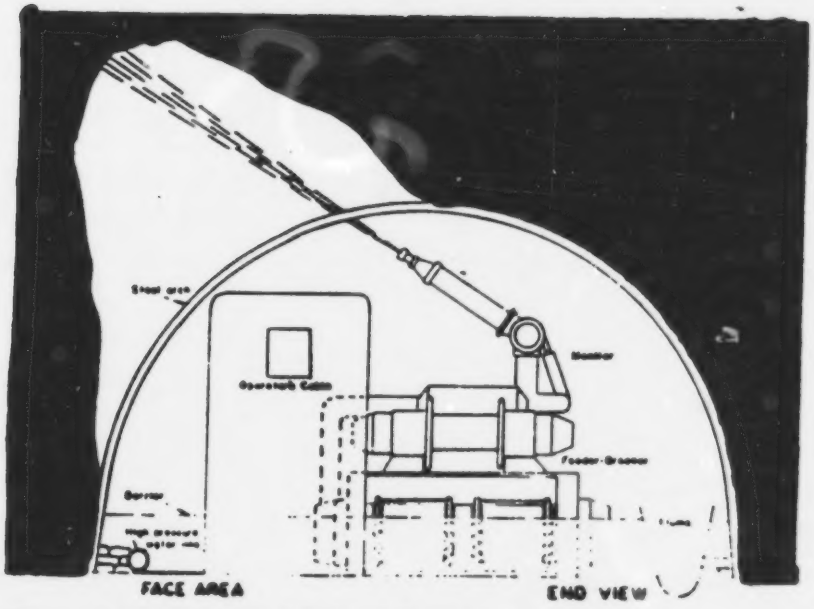


Fig. 3 HYDRAULIC MINE PANEL PLAN

FIGURE 4



FACE AREA PLAN VIEW



FACE AREA END VIEW

Fig. 4 Hydraulic Mine Sub-level Face Area

The initial field investigations were designed as shown in Figure 6. However, research work was quickly organized to meet the immediate requirements i.e. the measurement of the affected surface area above Panel 4A, before the snowfall. Subsequently arrangements were made for instrument installation, both in the affected area and the existing Panel 5A operation (Figure 7). During the 8 years of the program, requests for approval were submitted to senior management to commit funds for the first 3 years of the project, and again for the remaining 5 years. In addition to these funds, people were assigned to the program from both the operations and technical groups.

During the first 3 years of the project a training program of mine staff was inaugurated. The program was initially designed for the staff to become familiar with underground installations, followed by surface observations, and finally to visit Canmet's Calgary laboratory to acquire the knowledge and experience in assembling and calibrating instruments. Further training was carried out on data analysis to be used with the newly acquired mini computer.

Basically the program over the initial 3 years dealt with the development of field and laboratory testing of strata mechanics instrumentation and field techniques to measure the following:

a) Pillar deformation.
b) Load distribution on roadway support.
c) Strata movement above and below seam.
d) Roof to floor convergence.
e) Surface subsidence.

To continue with these research and development activities, consideration was given to the problems associated with methane emissions and spontaneous combustion, which are directly related to the geological structure, caving, ventilation and mining system. Emphasis was therefore given to sub-surface studies on regional geology in addition to studies on barrier pillars, determination of strata pressures on supports and behavior of caving.

But before proceeding further with the program, a 5 year detailed budgetary plan was developed outlining specific elements and objectives for each year or phase; this included manpower distribution and program responsibilities.

This 5 year plan to continue the program is outlined in the appendices in its original form.

The Plan also included the acquisition of drilling equipment, strata hole station equipment, ground control station equipment, outcrop pillar hole equipment and surface subsidence equipment.

FIGURE 5

FIGURE 5

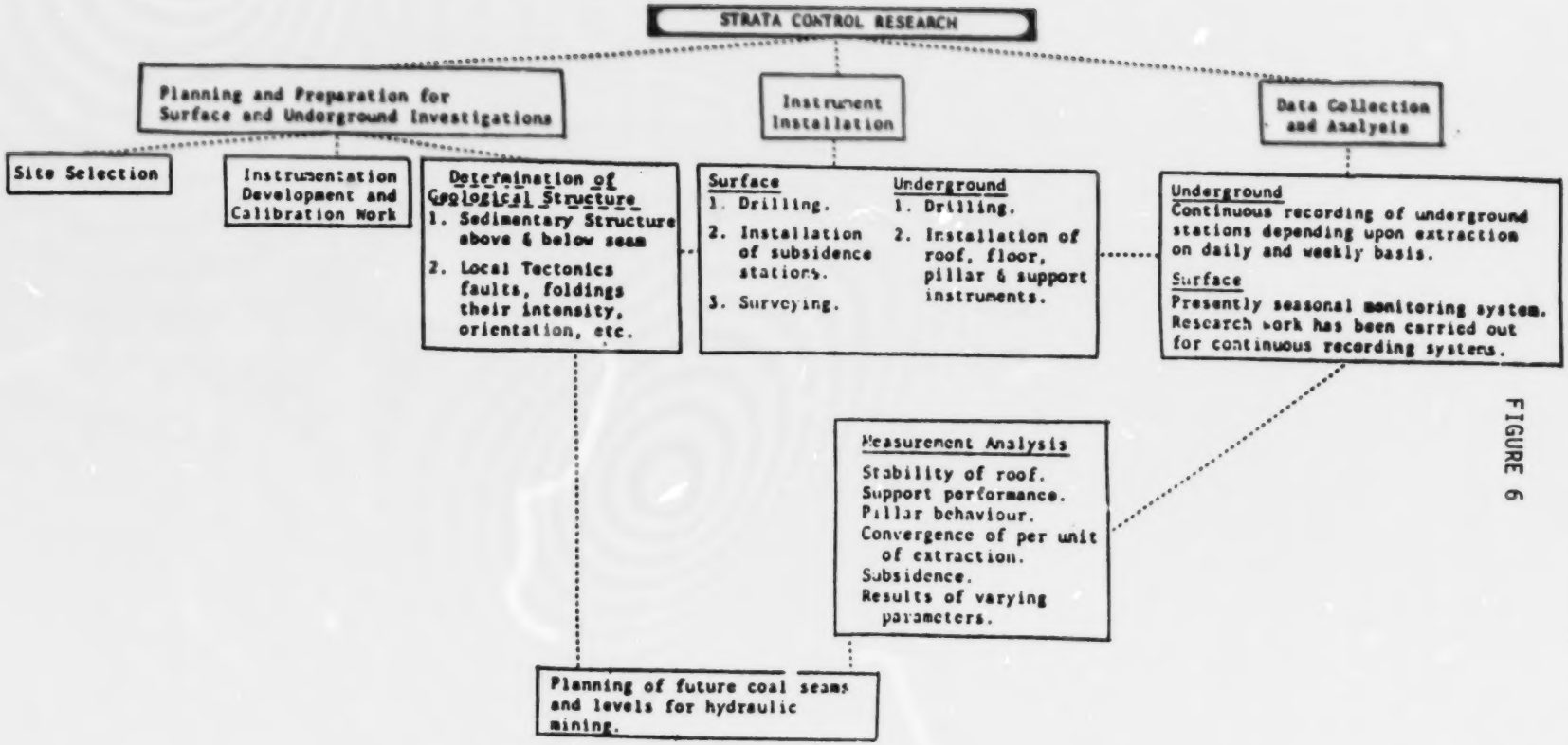

STRATA CONTROL RESEARCH
Planning and Preparation for Surface and Underground Investigations
Instrument Installation
Data Collection and Analysis
Site Selection
Instrumentation Development and Calibration Work
Determination of Geological Structure
1. Sedimentary Structure above & below seam
2. Local Tectonics faults, foldings their intensity, orientation, etc.
Surface
1. Drilling.
2. Installation of subsidence stations.
3. Surveying.
Underground
1. Drilling.
2. Installation of roof, floor, pillar & support instruments.
Underground
Continuous recording of underground stations depending upon extraction on daily and weekly basis.
Surface
Presently seasonal monitoring system. Research work has been carried out for continuous recording systems.
Measurement Analysis
Stability of roof.
Support performance.
Pillar behaviour.
Convergence of per unit of extraction.
Subsidence.
Results of varying parameters.
Planning of future coal seams and levels for hydraulic mining.

FIGURE 6

FIGURE 6 Program and Scope of the Strata Control Investigations at the Hydraulic Mine, 1975

FIGURE 7

FIGURE 7 : Surface topography and subsidence stations over the hydraulic mine (No. 4B Panel), Kaiser Resources Ltd., Sparwood, B.C.

2.6 Program Organization

The program was set up initially set up under John Shaw, Manager of Underground Engineering and Planning, who in turn designated Miss Wendy Bannerman, Mining Engineer, to oversee the engineering aspects. Mr. Jim Anderson, Mine Manager, appointed Mr. Jack Cowan responsible for installation work on behalf of the operating group.

The project organization depicting information flow is shown on Figure 44 (page 72).

SECTION 3

DISCUSSION

3.1 Subsurface

To understand the principle zones of strata movement as coal is extracted during the development and production stages, strata control stations were set up underground. These stations consisted of field instrument installations arranged to measure the following four major strata movements to determine their relationship to mining activities (Figure 8).

- roof to floor convergence
- pillar deformation
- bed separation in strata above and below the seam
- support loads

Figure 9 schematically illustrates the general pattern of roadway and sub-level development and extraction. The asterisks indicate the field measurement stations in the panel. Each station measures support loads, pillar deformation, roof to floor convergence and, if necessary, bed separation above and below roadway/sub-level (Figure 8).

Prime considerations in instrument selection were ease of measurement and accuracy. As well, they have to be well designed to resist the harsh mine environment and rough handling. Ideally the instruments should be reliable, accurate, light, easy to install, maintain, and retrievable for later reuse. The special requirements associated with the underground hydraulic mine were that:

- instruments must be safe for use in a coal mine. Electrical apparatus must be approved by the Inspector of Mines as intrinsically safe (or flameproof).

- instruments must function under very moist conditions in the hydraulic mine.

- instruments must have the expected measurement range.

3.1.1 Roof to Floor Convergence

The roadway deformation was determined by measuring the cumulative movement between two predetermined points in the roof and floor.

Initially, the method of installation was to anchor a pair of rock bolts into the roof and floor and permanently place a spring-set rod between them (Figure 10). The unit consisted of two telescopic tubes with a spring between them to allow 30 cm of movement as convergence between the ends occurred. Readings were taken manually from a scale on the conduit on a weekly basis. This method proved unsatisfactory, as the in-situ accuracy was low

FIGURE 8

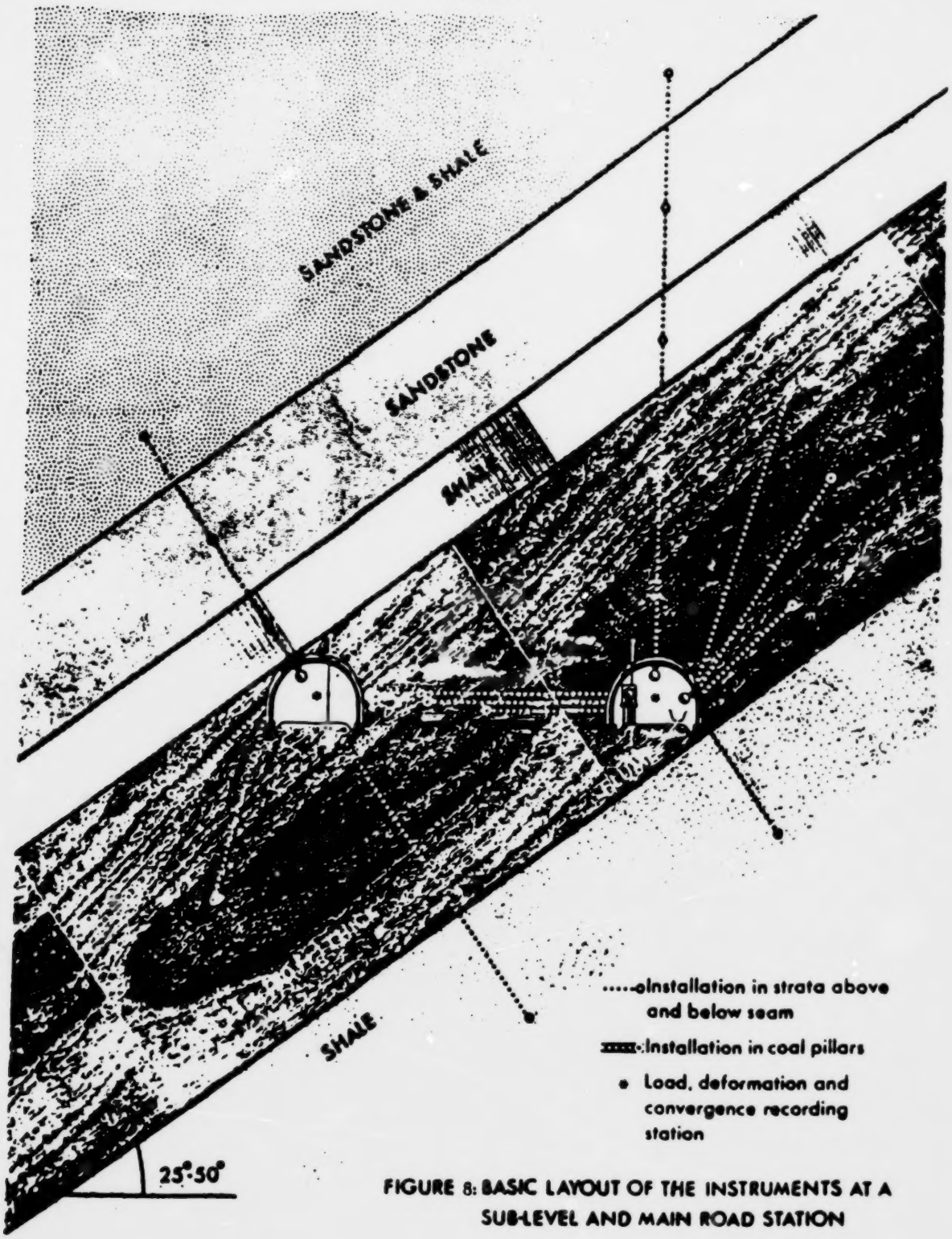
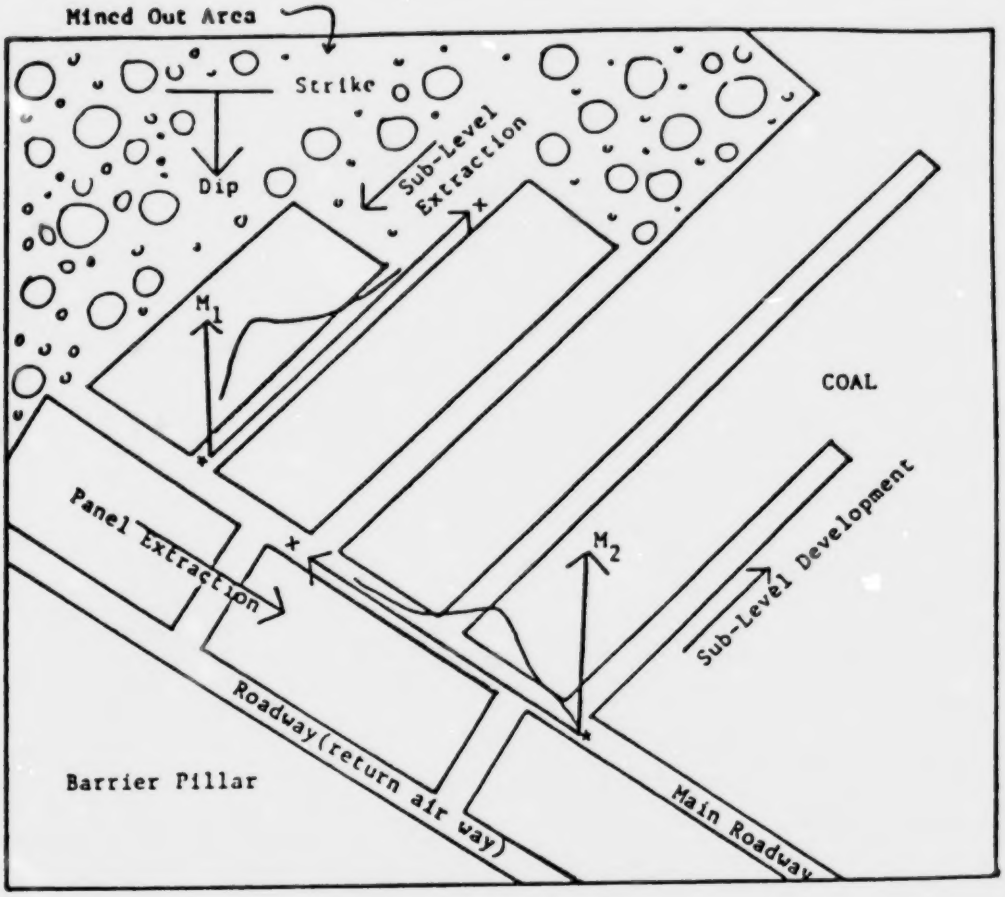


FIGURE 8: BASIC LAYOUT OF THE INSTRUMENTS AT A SUB-LEVEL AND MAIN ROAD STATION

FIGURE 9



* : strata mechanics (control) measurement station

x : time, distance, etc.

M_1 : measurement during sub-level extraction

M_2 : measurement during panel extraction

→ : direction

Figure 9 : Schematic Plan of Roadway and Sub-Level Development and Extraction in a Hydraulic Mine

FIGURE 10

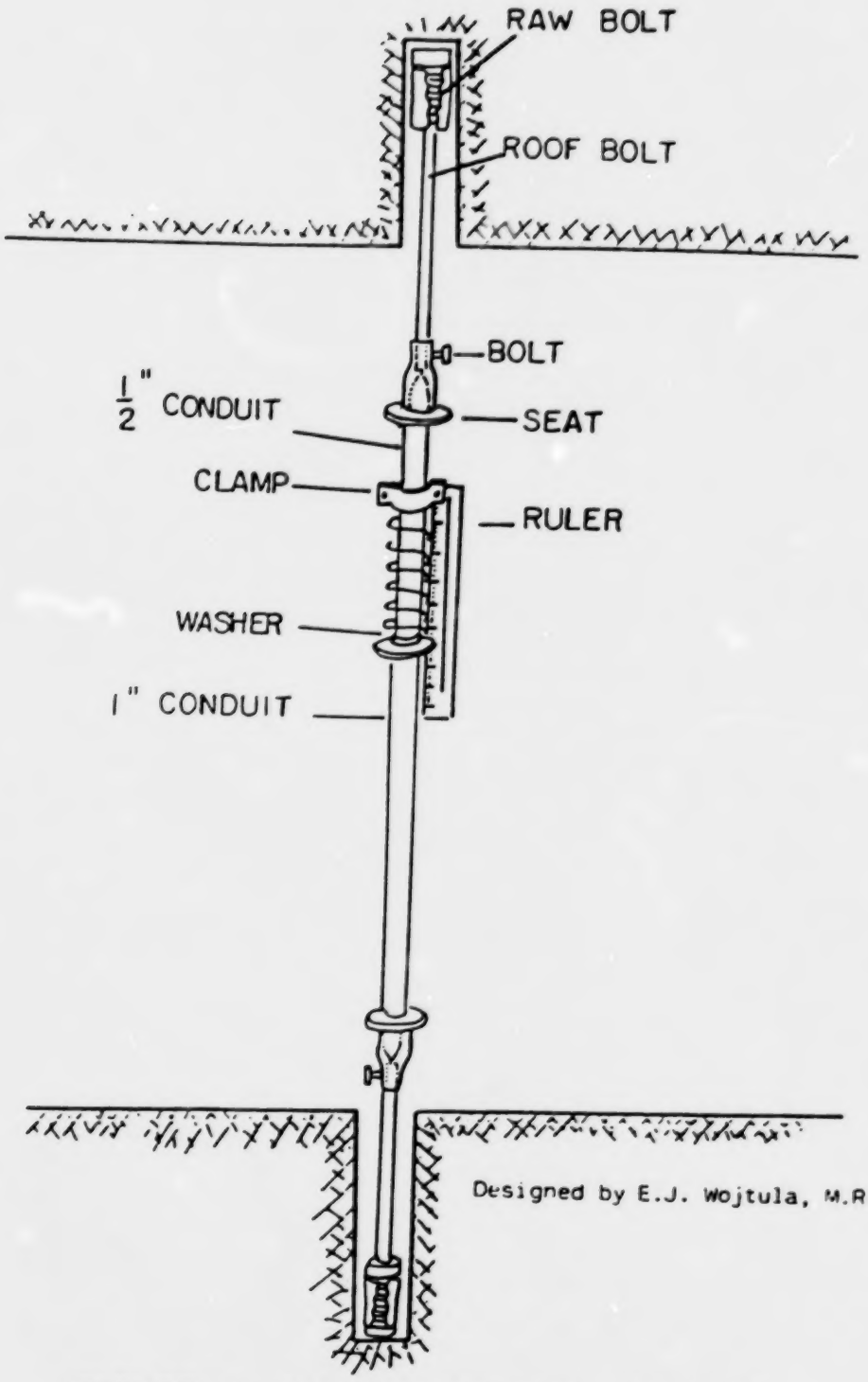


FIGURE 10 , DIAGRAM OF THE INSTALLED CONVERGENCE INSTRUMENT

($\pm$2mm) for long term data analysis using a computer. As well, the rods were soon bent or knocked out of place in the frequently used roadways.

Because of the fast moving extraction face, it was decided to modify the continuous recorder, and replace the spring set rod to measure convergence by means of a pulley and linkage system (Figure 11). The recorder was attached to a 2m pipe which was vertically secured in a 1m down hole. Movement of a transmission wire between anchor bolts and recorder could be detected continuously by the recorder via the pulley on a daily and/or weekly basis. The accuracy of the measurement, as estimated in the laboratory, was about $\pm$1mm. However, measurements in the field indicated lower accuracy (approx. $\pm$2 - 3 mm) and lower sensitivity, possibly due to slippage between the pulley and transmission wire.

The current method is to use a constant-tension tape (accuracy approx. $\pm$1 mm) between the pair of bolts for each convergence measurement. This has proved satisfactory in terms of accuracy and convenience.

3.1.2 Pillar Deformation

Pillar deformation was determined by measuring relative axial movement of a transmission wire between a borehole collar and a rawl-plug anchored within the pillar at a known depth. It was assumed that a pillar under induced load would form a relatively fractured zone at the edge, but with a confined core.

For stations installed in sub-levels, the usual pillar width is about 25m. Three pillar holes of 4.45cm diameter were drilled per station to depths of about 7m, 12m and 16m. The holes were usually drilled at a positive angle (5^{o} to 30^{o} from the horizontal) in order to keep them inside the coal seam. The borehole length and inclination were limited by the compressed air hand-held auger drill.

A continuous recorder was modified for measuring pillar deformation in a way similar to that detailed in Section 3.1.1, except that it was attached to a 2m pipe, half of which was secured in the pillar hole. The results were again unsatisfactory due to low accuracy and low sensitivity.

A transmission rod was tried instead of the wire for direct and manual reading. The accuracy was considered inadequate ($\pm$1 mm) for long term computer analysis of data.

The method that proved to be satisfactory measures the movement of a transmission wire between the anchor and collar station of the drill hole using a Newcastle MKII extensiometer which provides an accuracy of about $\pm$0.05 mm (see Figure 12). Two values of tension (- 6.8 and 9 kg) are applied to each measurement to improve the accuracy.

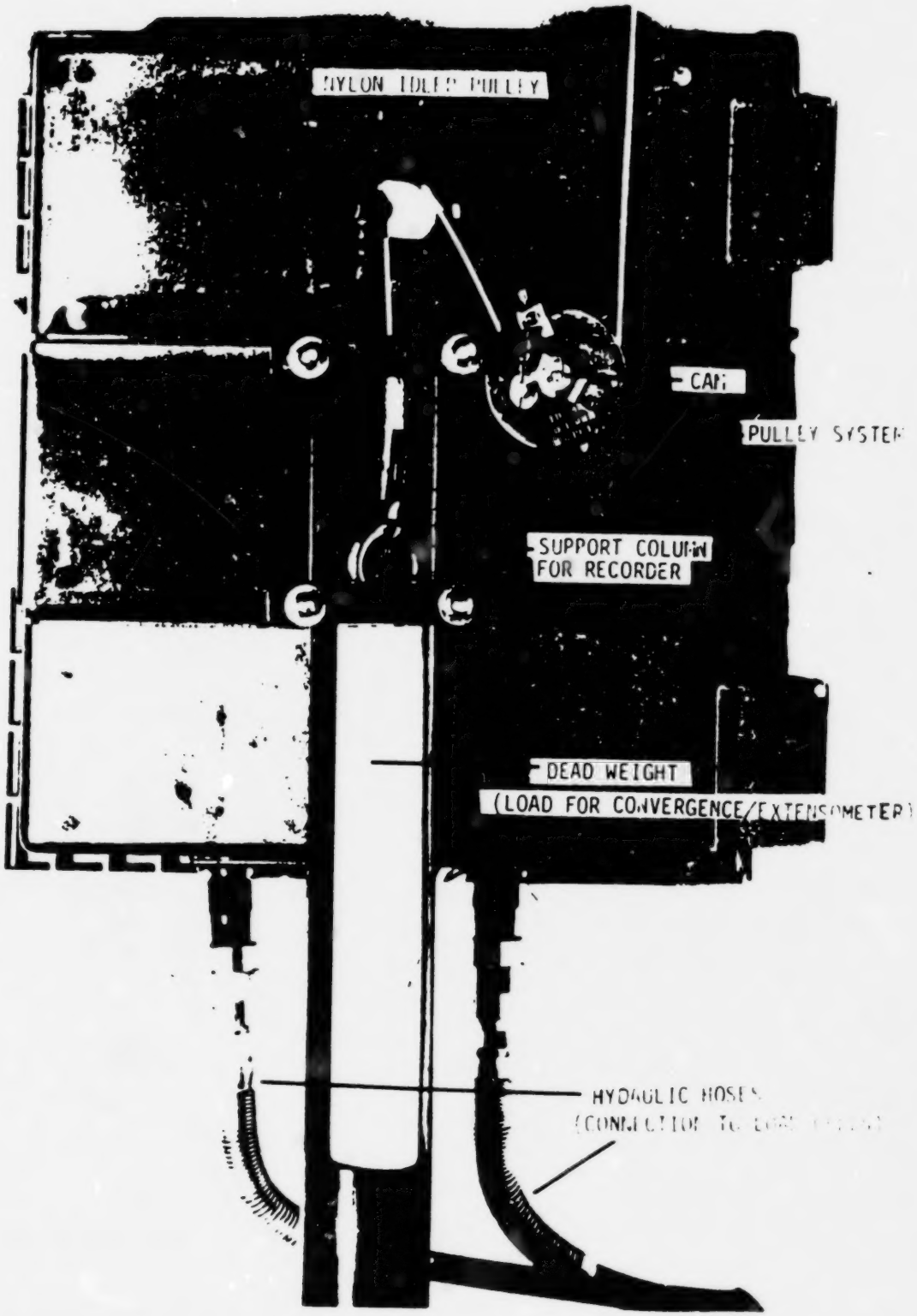


FIGURE 11: BACK VIEW OF THE NEW RECORDING UNIT FOR MEASUREMENTS OF [illegible] LOADS AND CONVERGENCE DEFORMATION

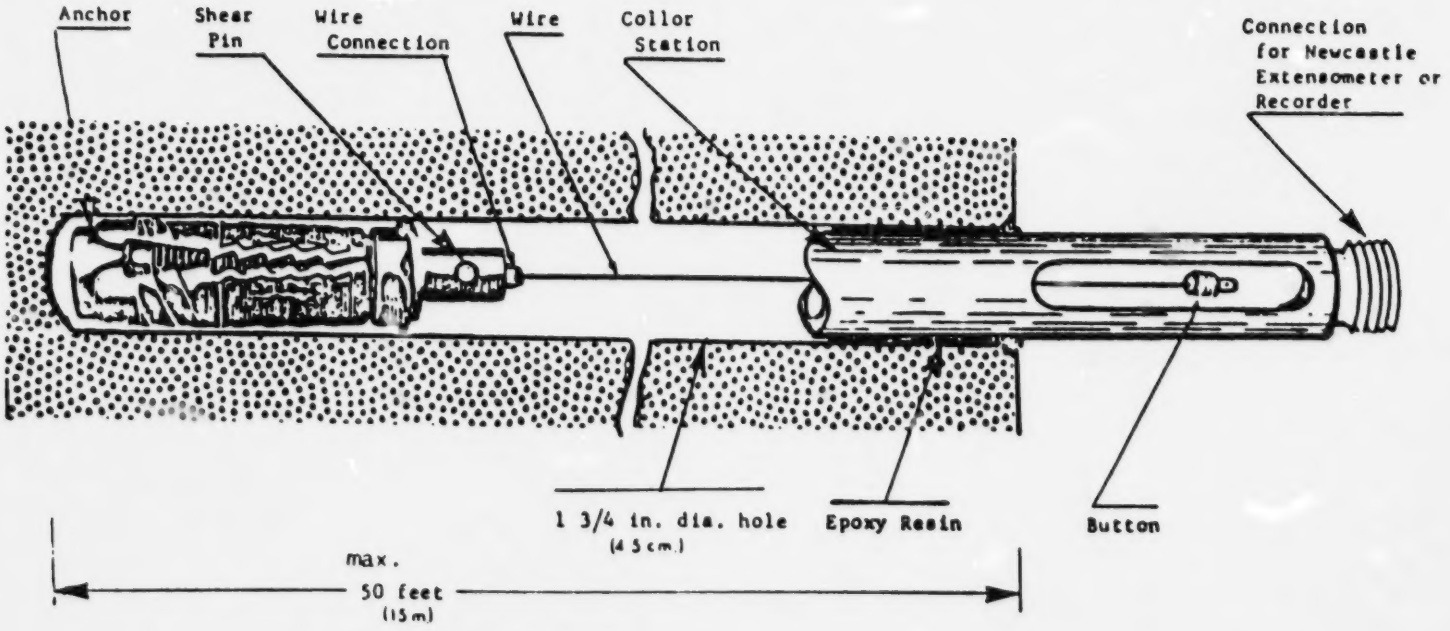


FIGURE 12

FIGURE 12 : Diagram of the Installed Wire Extensometer.

3.1.3 Bed Separation in Strata Above and Below Seam

The method consists of installing 3 anchors at intervals along a borehole drilled into roadway strata approximately 40m above and 6-10m below. The position of measuring sections is selected according to lithology and structure. During drilling operations into strata above and below, immediate analysis of core samples is made so that possible locations of these measuring sections can be decided according to the change in lithology and structure. Figure 8 shows the general set-up of these measuring sections. It is also important to note the change in lithology and structure within the present workings in order to relate the results of measurements with strata structure.

The method of measuring strata movement is carried out with a borehole extensiometer. Basically, it measures the differential axial movement between the points in the borehole and the borehole collar. Three wires anchored at different depths (approx. 20m, 30m and 40m from the borehole collar) were installed in the borehole strata above, and one anchored (6-10m) in the strata below, as a standard reference length between measured sections and borehole collar.

3.1.4 Support Load

Load measuring requirements were that:

- the load cell must be capable of being mounted within any type of support;
- it must allow for eccentric loading;
- it must function under the moist conditions of the hydraulic mine.
- it must form an integral part of the support system.

In order to fulfill the above requirements, some modifications were made to commercially available equipment. The load cell (Figure 13) consisted of a cast iron cylinder containing a steel piston with an effective area of 71.26 cm^2, which was loaded through a tilting head. In order to ensure that the body was always loaded in the same manner irrespective of the nature of loading, a steel frame housing was built to hold the load cell and the roadway support. The load cell and the support were secured to the steel frame by means of safety bolts. This method of assembly allowed for the load cell to be used under eccentric loading to 10^0 from the vertical axis without damage.

Where the strata control stations were located in an arch leg, support load was monitored by connecting the load cells to a high pressure continuous recorder. For those strata control stations located in roadways driven along the hanging wall and supported by roof bolts, a load cell was placed between the hanging wall and a

FIGURE 13

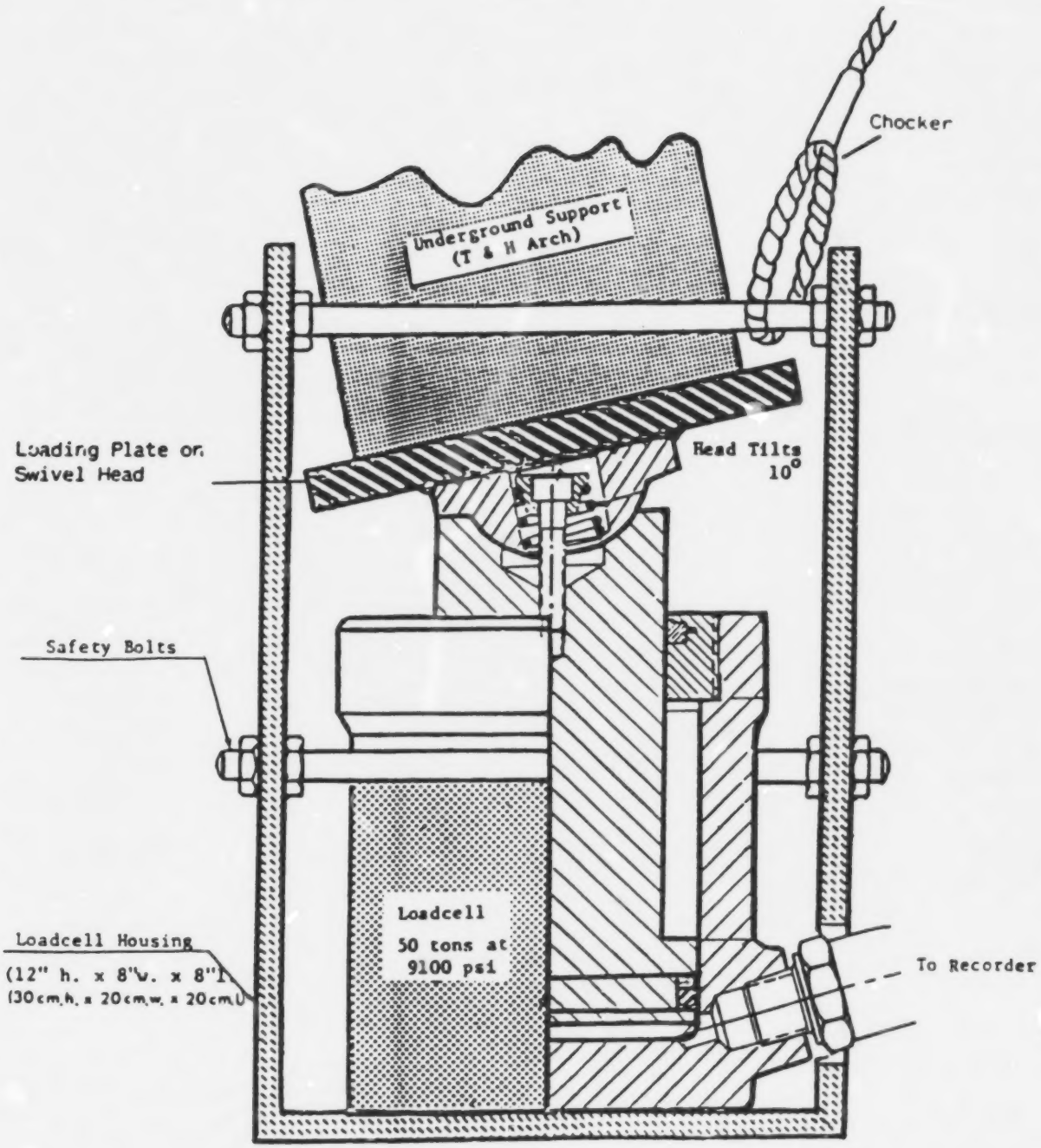


FIGURE 13 : The New MRL Support Loadcell Arrangement using OTC Cell

wooden post. The measurement ensured the competence of support systems and aimed at determining the load redistribution in relation to mining activities. Two load cells (50 tonne hydraulic rams) were used per station.

When the load cell was installed beneath an arch leg, both cell and leg were set in the steel housing which also acted as a base plate and prevented slippage of the arch leg off the load cell.

The load cells were then connected by hydraulic hoses to a high pressure continuous recorder (0-300 kg/cm2, accuracy approx. $\pm$1%). Two pressure elements located within the recorder converted the changes of internal pressure into mechanical movement. The recording was made on the basis of 24 hour or 7 day cycles.

3.1.5 Station Locations

After extensive evaluation by Canmet scientists of instrument capabilities and their techniques of application, the following stations were set up underground (see Figure 14 for stations R1 to R7 in Panel 5 and Figure 15 for stations PCR1 located in Panel 6).

Stations R8, R9 and R10 were installed, but due to the fast extraction of the final pillars in Panel 5, no results were tabulated.

3.1.5 (a) Station R1 - No. 5 Panel (Figure 16)

Strata control station R1 was installed in No. 1 entry in December 1977. At the station site, the entry is located in midseam and has a depth of cover of 240m.

Three boreholes were drilled and anchored at depths of about 4.4m, 5m and 9.4m at 0° into the coal pillar on the down-dip side of the entry.

Two load cells were placed 5m apart, on the down-dip side of the entry, beneath the roadway arch support (BSC 29 kg/m) yieldable arch.

A convergence rod, set between the roof and floor, was knocked out of place and destroyed soon after being installed.

The high pressure continuous recorder was removed prematurely because a raise, driven from No. 2 to No. 1 entry, broke through at the station site. Pillar deformation measurements continued until termination of the station due to extraction.

Station load measurements were terminated in March 1978, and that of pillar deformation was completed in August 1978. Results of measurements are illustrated in Figures 24, 25, 26, 27 and 28.

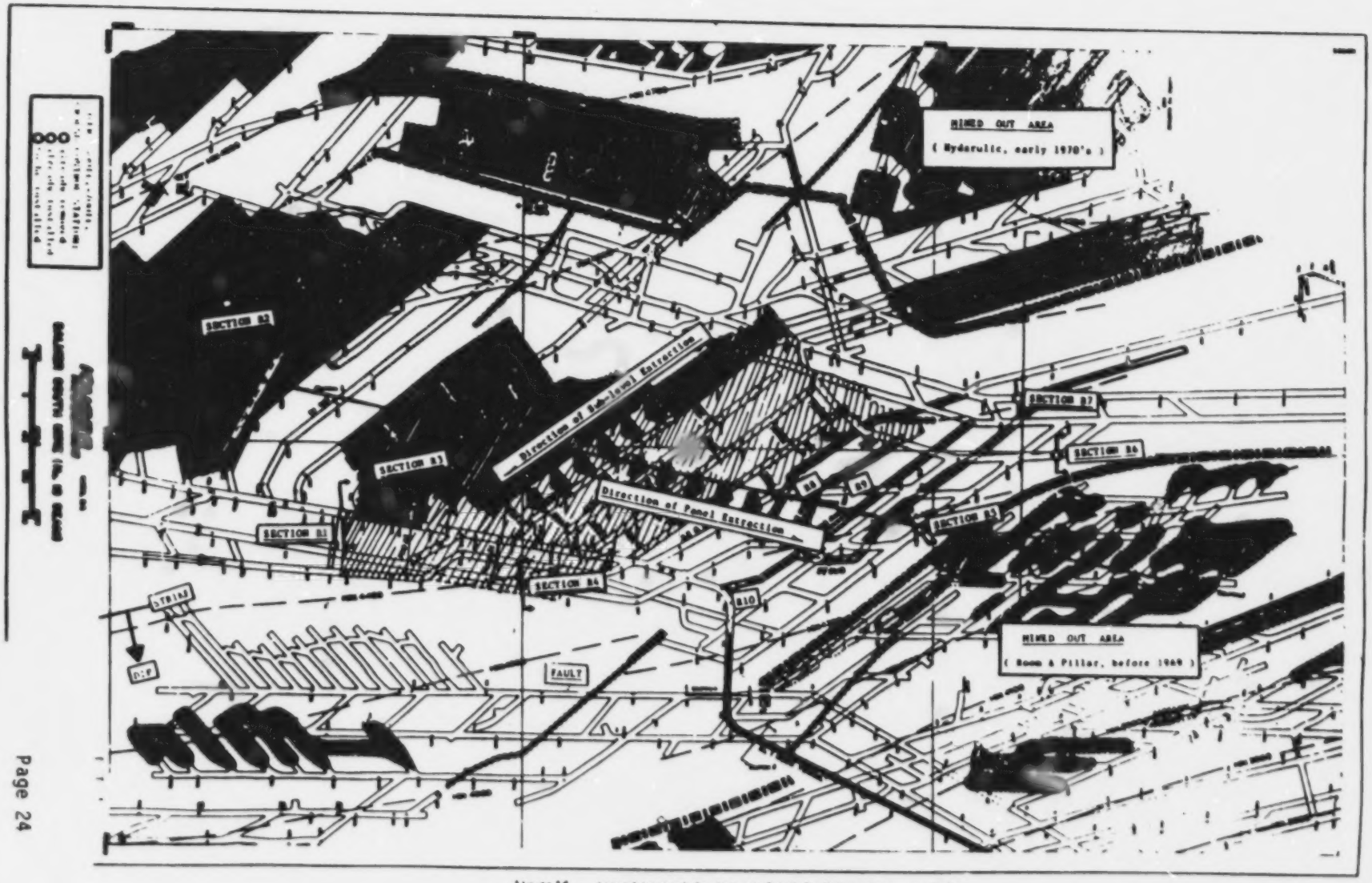
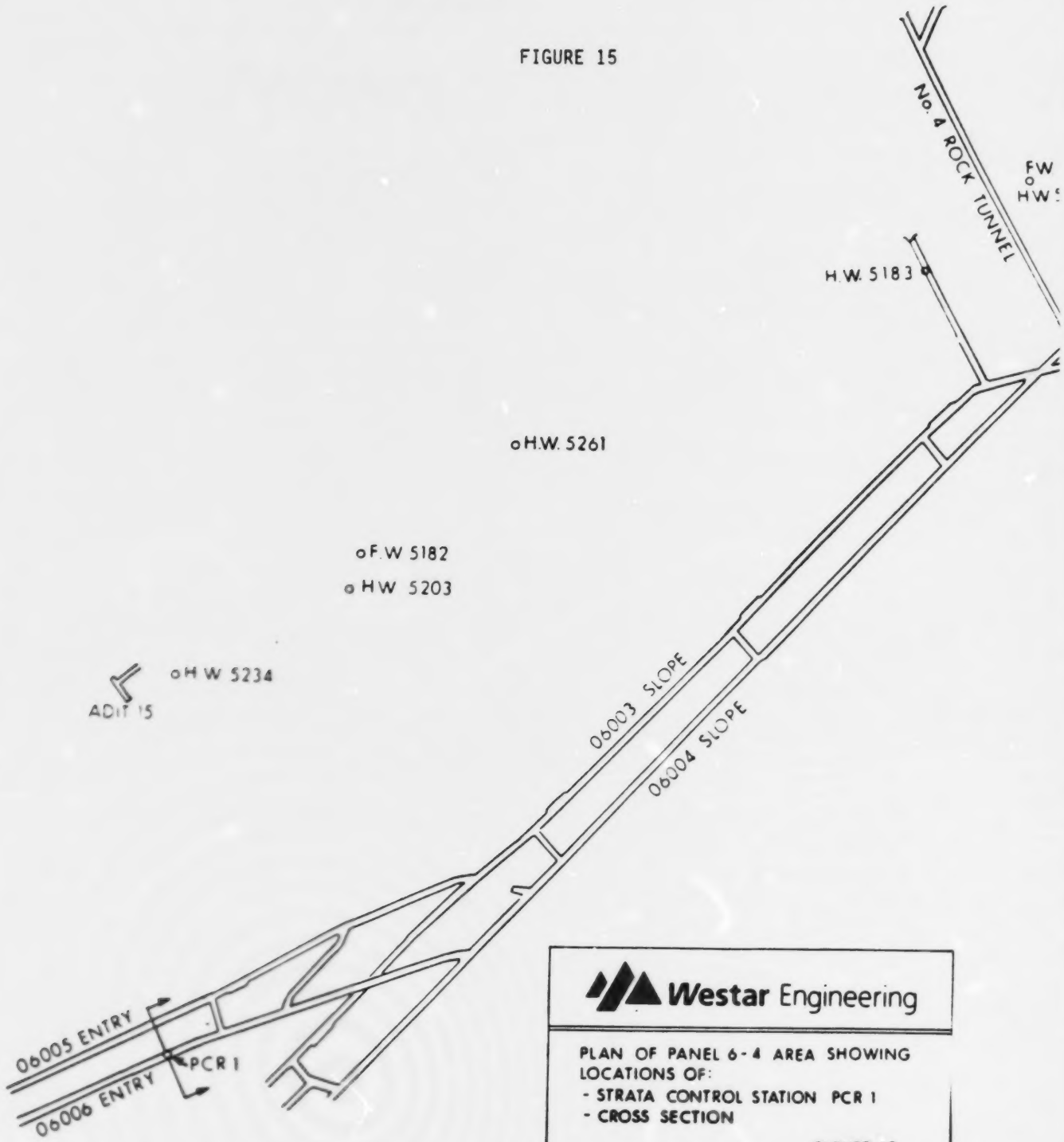


Figure 14 Ground Control Studies at Panel 5, Kaiser Resources Ltd (1977-1979)

FIGURE 15



Westar Engineering

PLAN OF PANEL 6-4 AREA SHOWING LOCATIONS OF:
- STRATA CONTROL STATION PCR 1
- CROSS SECTION

FIGURE 15

STATION R1 - Depth 710 ft
- Installation date: Nov. 1977
- Termination date: support load measurement - Mar. 1978
pillar def. measurement-Aug. 1978

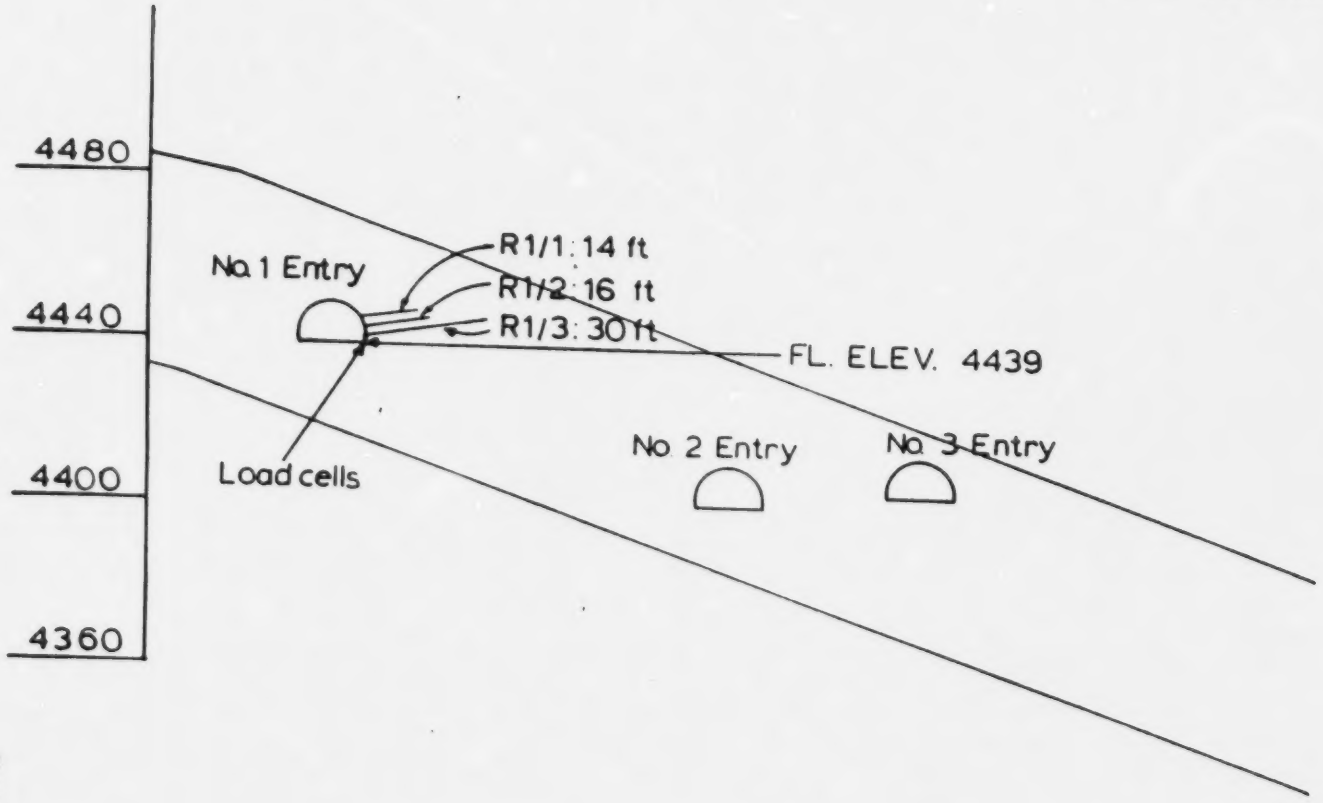


FIGURE 16

Scale 1" = 40'
U/G ENG.
Dec.' 78

FIGURE 16

3.1.5 (b) Station R2 - No. 5 Panel (Figure 17)

R2 was installed in 20 sub-level during August 1977 and terminated in September 1977. The sub-level at the station site was positioned at midseam and had a depth of cover of 280m.

Two pillar holes were drilled on the up-dip side of the entry, into the coal pillar to be extracted.

The load cells were placed beneath the arch support (BSC 29 kg/m) yieldable arch positioned on the up-dip (extraction) side of the entry.

Due to unforeseen mining problems, R2 was lost and data collected at the time was insufficient for analysis.

3.1.5 (c) Station R3 - No. 5 Panel (Figure 18)

R3 was installed in May 1977 and terminated in May 1978. In 25 sub-level, an old entry driven in 1974, at the station site the entry was positioned near the footwall and had a depth of cover of 240m. The seam in this area thickens from about 13m (near 25 sub-level) to 20m.

Three up-holes were drilled into the coal pillar to be extracted, on the up-dip side of the sub-level, and anchors located at depths of about 6.2m at 30^{0}, 10.5m at 33^{0} and 12m at 20^{0}.

Two load cells were installed about 5m apart, beneath BSC 29 kg/m yieldable arches, both on the up-dip (extraction) side of the sub-level. Except for the initial 83m of 25 sub-level which was supported by the BSC yieldable arch, the remainder was supported by 3 piece rigid Hollybank supports.

Results of measurements are illustrated in Figures 24, 25, 26, 29, 30, & 31.

3.1.5 (d) Station R4 - No. 5 Panel (Figure 19)

R5 was installed in February 1978. The site, located in No. 2 entry, was at midseam and had a cover depth of 215m.

Two up-holes were drilled into the coal pillar on the up-dip side of the entry, at depths of about 10m at 25^{0} and 12.5m at 20^{0}. Coal was extracted from No. 2 entry on both sides of the entry.

Two load cells were placed under the BSC 29 kg/m yieldable arch, one on each side of the roadway. No convergence measurement site was installed.

Results of measurements are illustrated in Figures 24 and 26.

STATION R2 - Depth 845 ft.
- Installation date: Aug. 1977
- Termination date: Sept. 1977

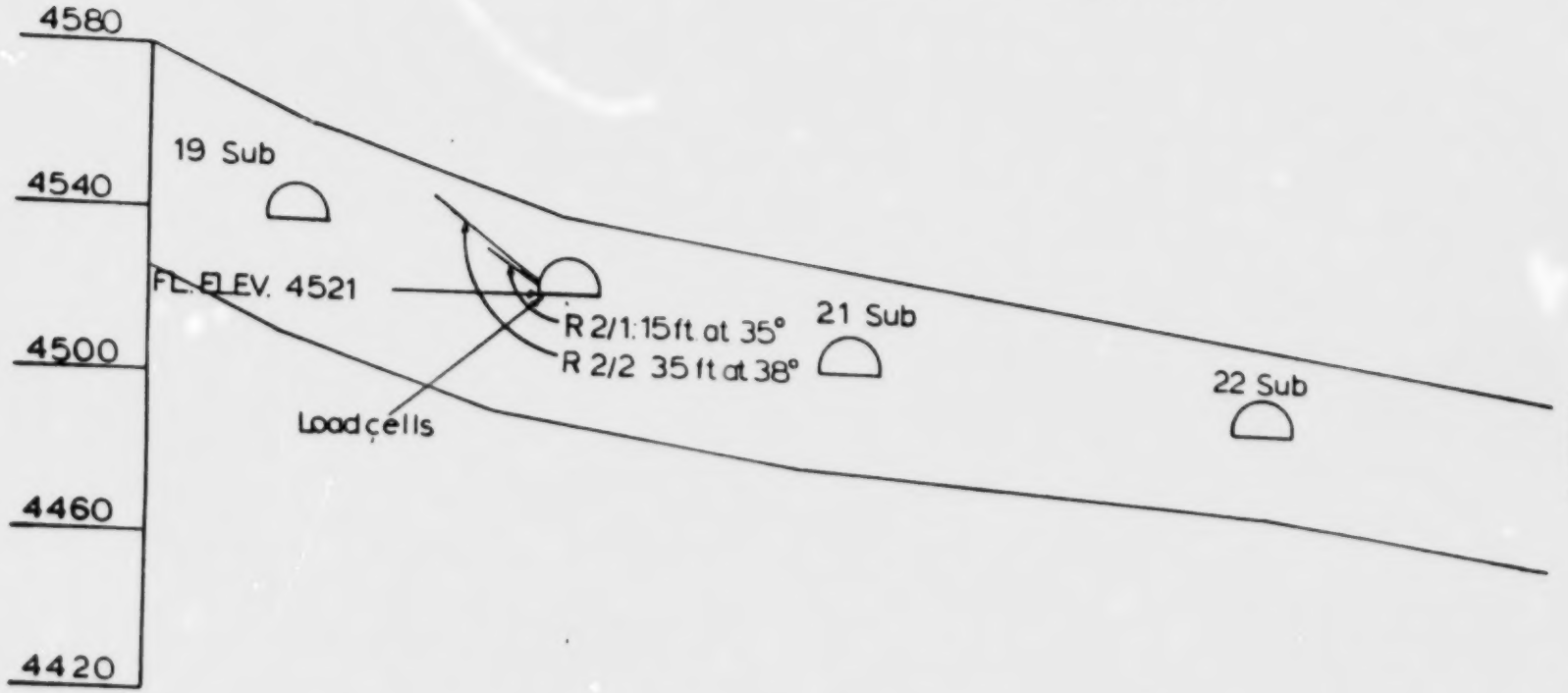


FIGURE 17

Scale 1" = 40'
U/G ENG.
Dec. '78

FIGURE 17

STATION R3 - Depth 710 ft
- Installation date - May 1977
- Termination date - May 1978

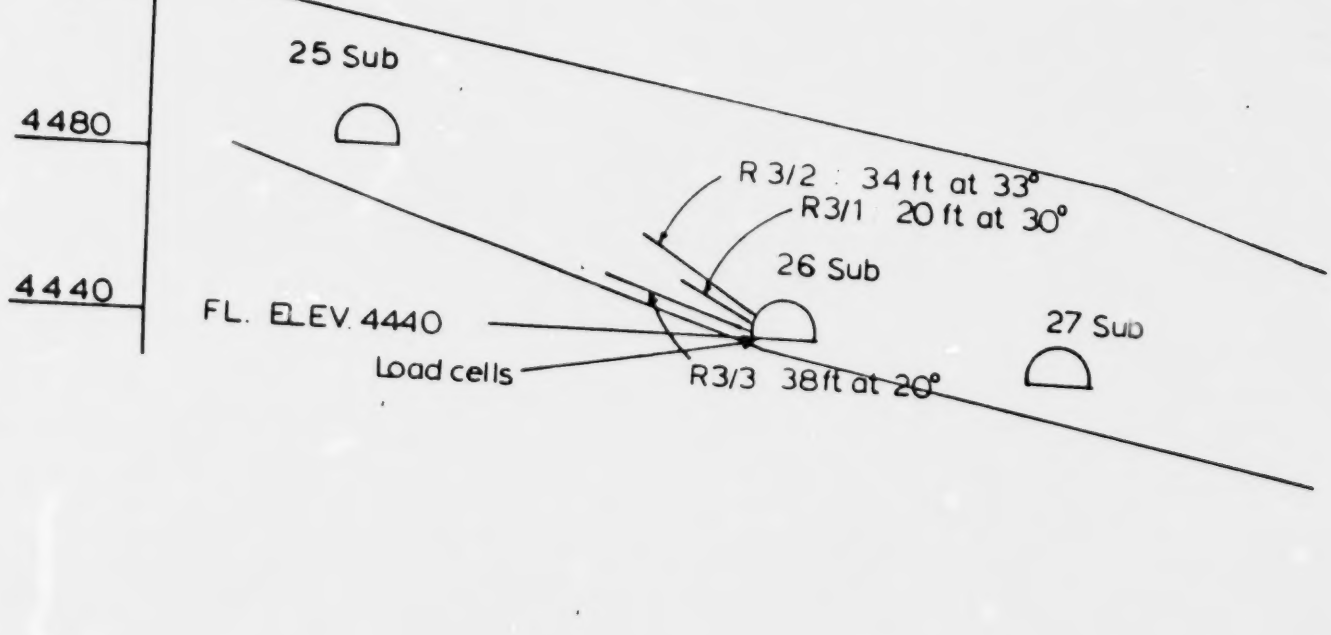


FIGURE 18

Scale 1" = 40'
U/G ENG
Dec 78

FIGURE 18

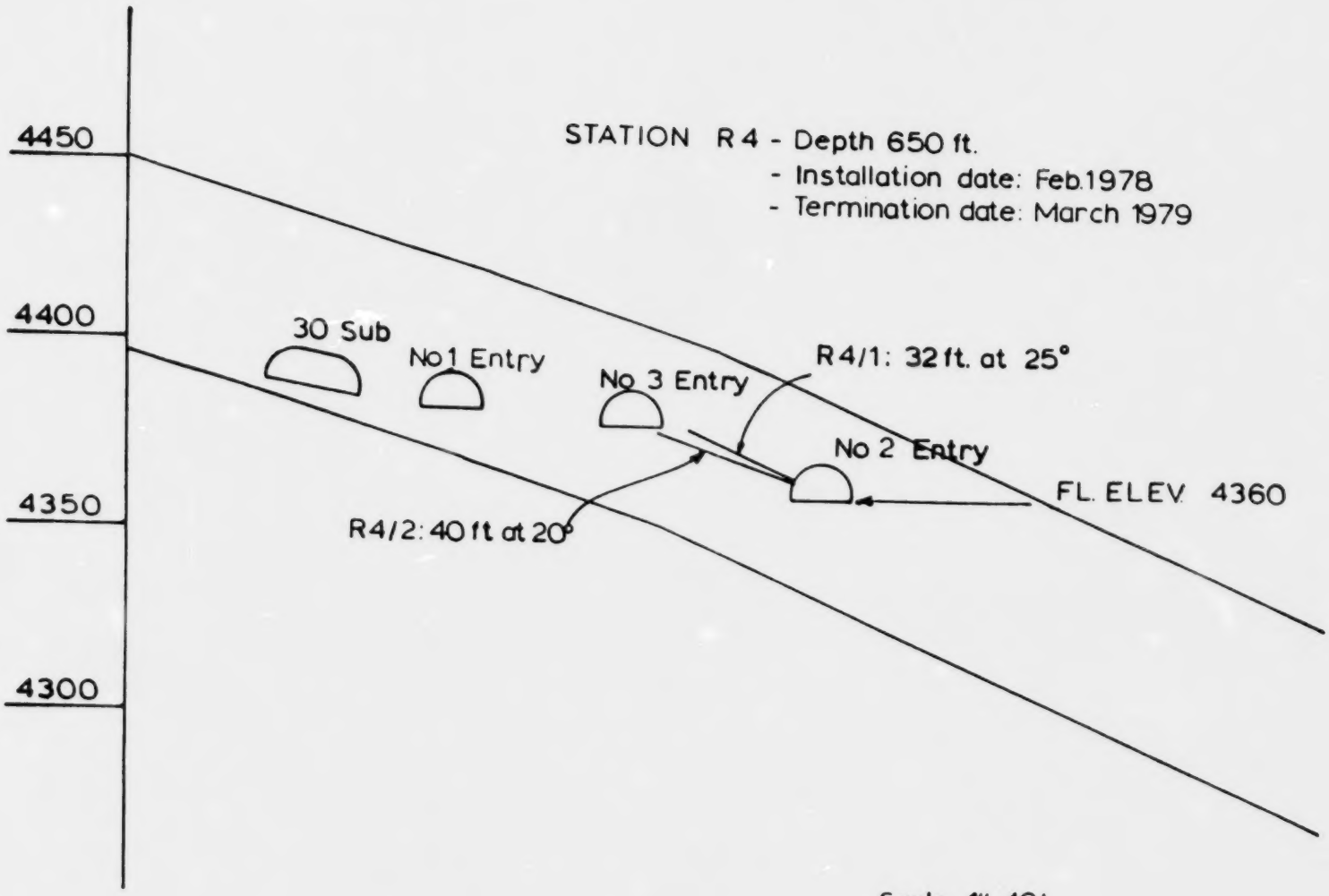


FIGURE 19

FIGURE 19

3.1.5 (e) Station R5 - No. 5 Panel (Figure 20)

R5 was installed in August 1978 in an old entry driven in 1969. This entry was located along the hanging wall (shale) and had a depth of cover of 135m at the station site.

Roof bolts, installed on 1.3m centres, and wood posts set at random, provided the roof support. Old workings mined during early 1970's were approximately 25m down-dip from the station.

Three up-holes were drilled into the coal pillar on the up-dip side of the entry at depths of about 4.2m at 5^{o}, 6m at 6^{o} and 9m at 5^{o}. One pillar deformation wire was monitored by the high pressure continuous recorder. Extraction of the coal pillar was from a sub-level driven near the footwall, below the old entry. The seam in this area was estimated to be 23m thick.

Two load cells were wedged between the hanging wall and wood posts; one on the high side (up-dip) of the entry, the other on the low side (down-dip).

Two convergence measurement sites were located at the high side and low side of the entry.

Results of measurements are illustrated in Figures 24, 25 and 26.

3.1.5 (f) Station R6 - No. 5 Panel (Figure 21)

R6 was installed in August 1978, situated in an old entry, driven in 1970 along the hanging wall. The depth of cover at the station site was 93m.

The roof support was the same as described for station R5. These up-holes were drilled into the coal pillar on the up-dip side of the entry at depths of about 7.2m at 21^{o}, 10.6m at 1^{o} and 15m at 11^{o}. One pillar deformation wire was monitored by the continuous high pressure recorder. Extraction of the pillar was from a sub-level located near the footwall, below the entry. Old workings were situated 67m down-dip from the station site.

The load cell and convergence installations were similar to those in R5.

Results of measurements are illustrated in Figures 24, 25 and 26.

3.1.5 (g) Station R7 - No. 5 Panel (Figure 22)

R7 was installed in August 1978, and was located in an old entry driven in 1969. The entry at the station site was near the footwall and had a cover depth of 115m. The roadway was supported by BSC 29 kg/m yieldable arches.

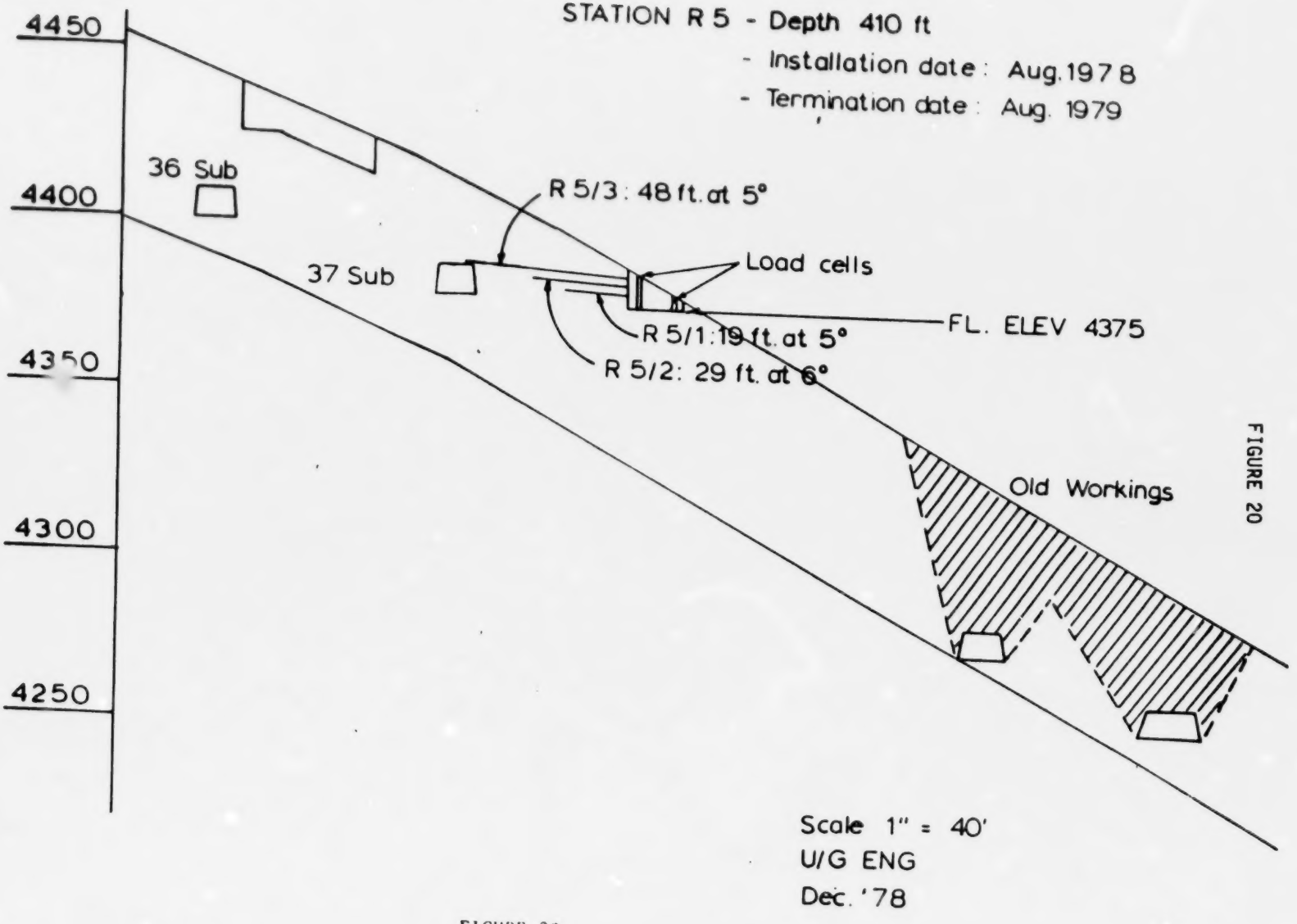
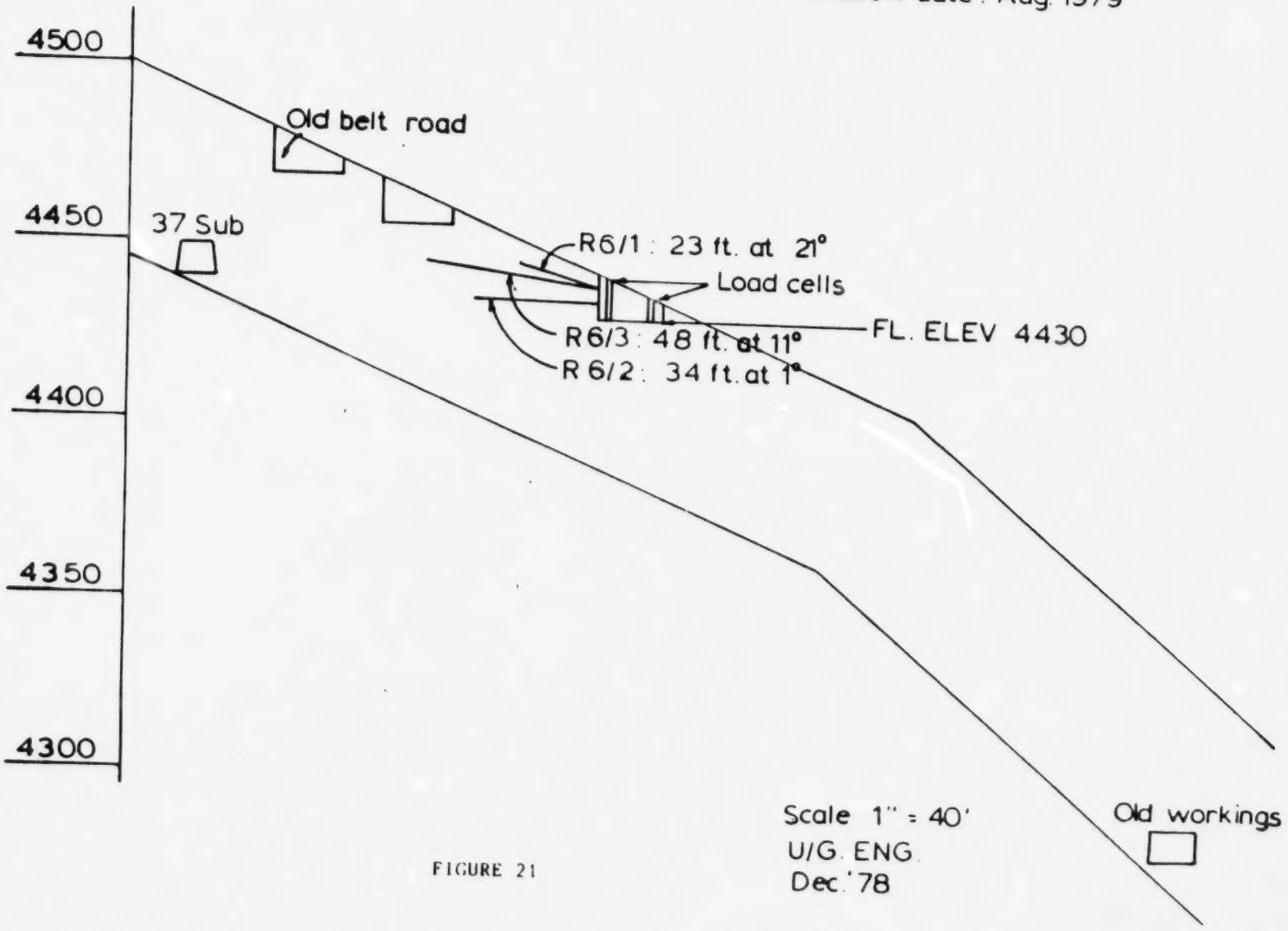

STATION R 5 - Depth 410 ft
- Installation date : Aug. 1978
- Termination date : Aug. 1979
4450
4400
4350
4300
4250
36 Sub
37 Sub
R 5/3 : 48 ft. at 5°
Load cells
FL. ELEV 4375
R 5/1 : 19 ft. at 5°
R 5/2 : 29 ft. at 6°
Old Workings
Scale 1" = 40'
U/G ENG
Dec. '78

FIGURE 20

STATION R6 - Depth 280 ft.
- Installation date: Aug 1978
- Termination date: Aug. 1979



Scale 1" = 40'
U/G. ENG.
Dec. '78

FIGURE 21

FIGURE 21

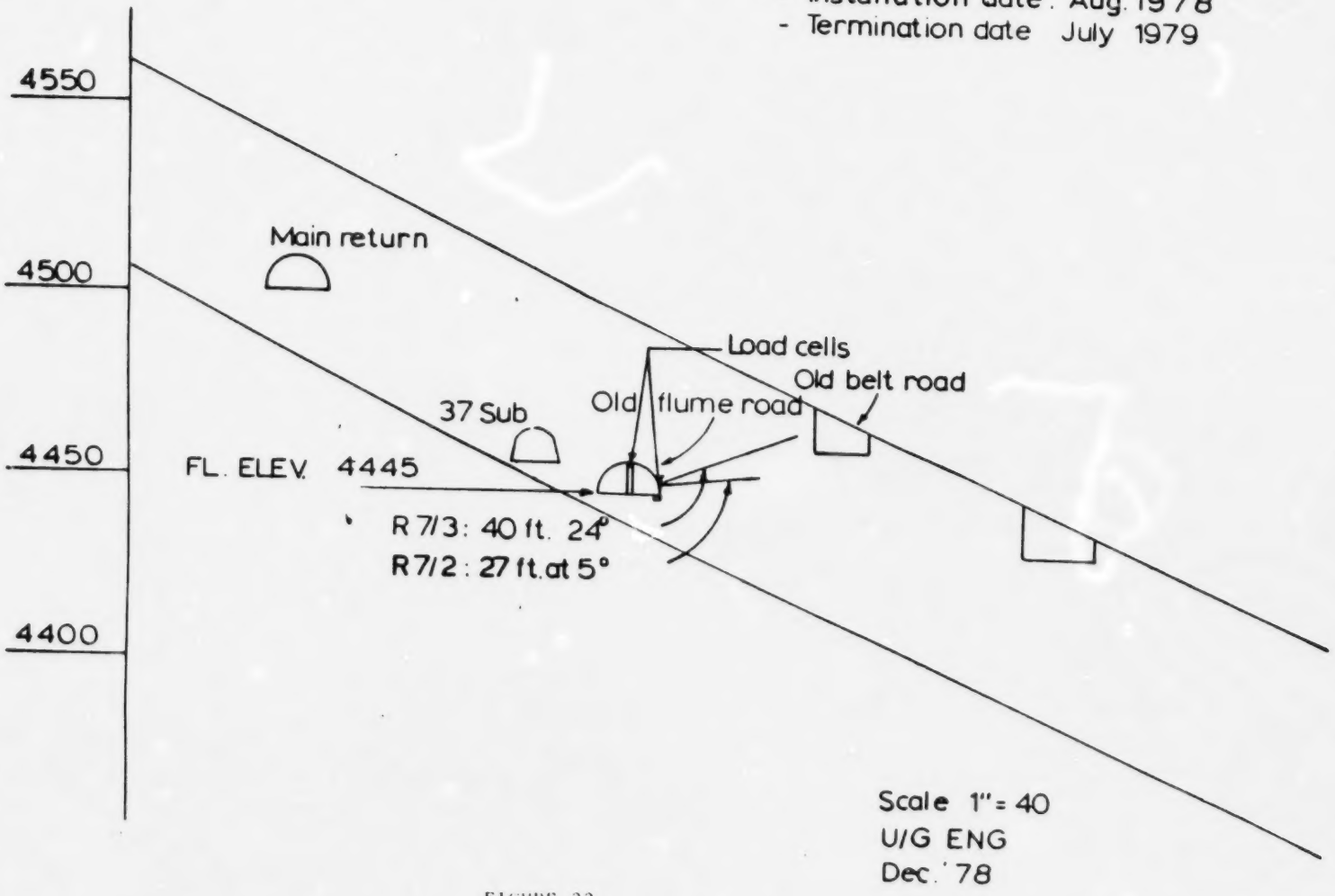


FIGURE 22

FIGURE 22

Two up-holes were drilled into the coal pillar on the down-dip side of the entry at depths of about 12.5m at 24° and 8.4m at 5°. The pillar was extracted from a sub-level to be driven below the entry.

Two load cells were installed: one placed beneath an arch leg on the down-dip side of the entry, and the other wedged between a wood post and the coal roof in the center of the entry. Two convergence sites were drilled at each side of the entry.

Results of measurements are illustrated in Figures 24, 25 and 26.

3.1.5 (h) Station PCR1 - No. 6 Panel (Figure 23)

PCR1 was installed in January 1978 in 06006 main entry, No. 6 Panel. This station measured only the effects of development on the strata since No. 6 Panel mine was still in the development stage. The 06006 entry at the station site was located midseam at a depth of 446m.

Three up-holes were drilled into the coal pillar on the up-dip side of the entry at depths of about 3.1m at 20°, 6.2m at 20° and 9.4 at 20°.

Two load cells were placed under BSC 29 kg/m yieldable arches, one at each side of the entry.

One convergence wire was anchored into the coal seam roof and was continuously monitored by the station recorder.

Results of measurements are illustrated in Figures 24 and 26.

3.1.6 Review of the Subsurface Monitoring Results

Field measurements were taken during the initial, middle phase and the end of the coal extraction in Panel 5 and are plotted in Figures 24-26 which represent maximum values of convergence, support load, pillar and strata deformation. Coal extraction during this period was carried out in sub-levels 250 meters long.

The support loads measured on the arches showed that the arches fitted with the instruments rarely reached yield loads. Maximum loads were approximately 11 metric tons (24,000 lb) in the sub-level and approximately 4.5 metric tons (10,000 lb) in the main road. Some of the arches were seen either sliding over each other or penetrating the floor before the designed yield value was reached, due to random torque applied during setting of these arches. As a precaution, arrangements were made to tighten the clamps to a torque of 25 - 28 kg-m (180-200 ft-lb) so that sliding resistances could be controlled.

It can also be seen that there was little change in average maximum convergence and the maximum value was 60mm at the closest

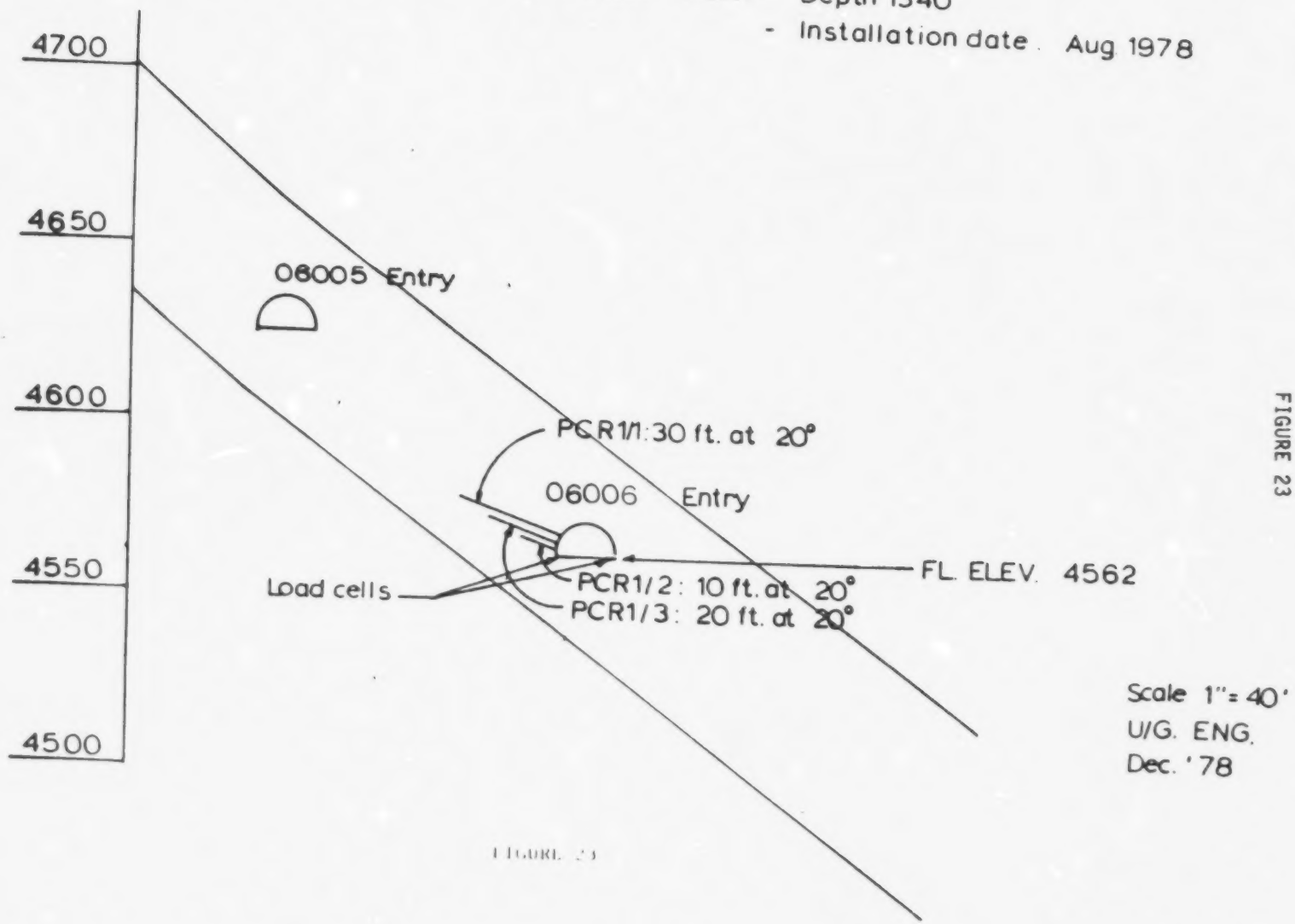


FIGURE 23

FIGURE 23

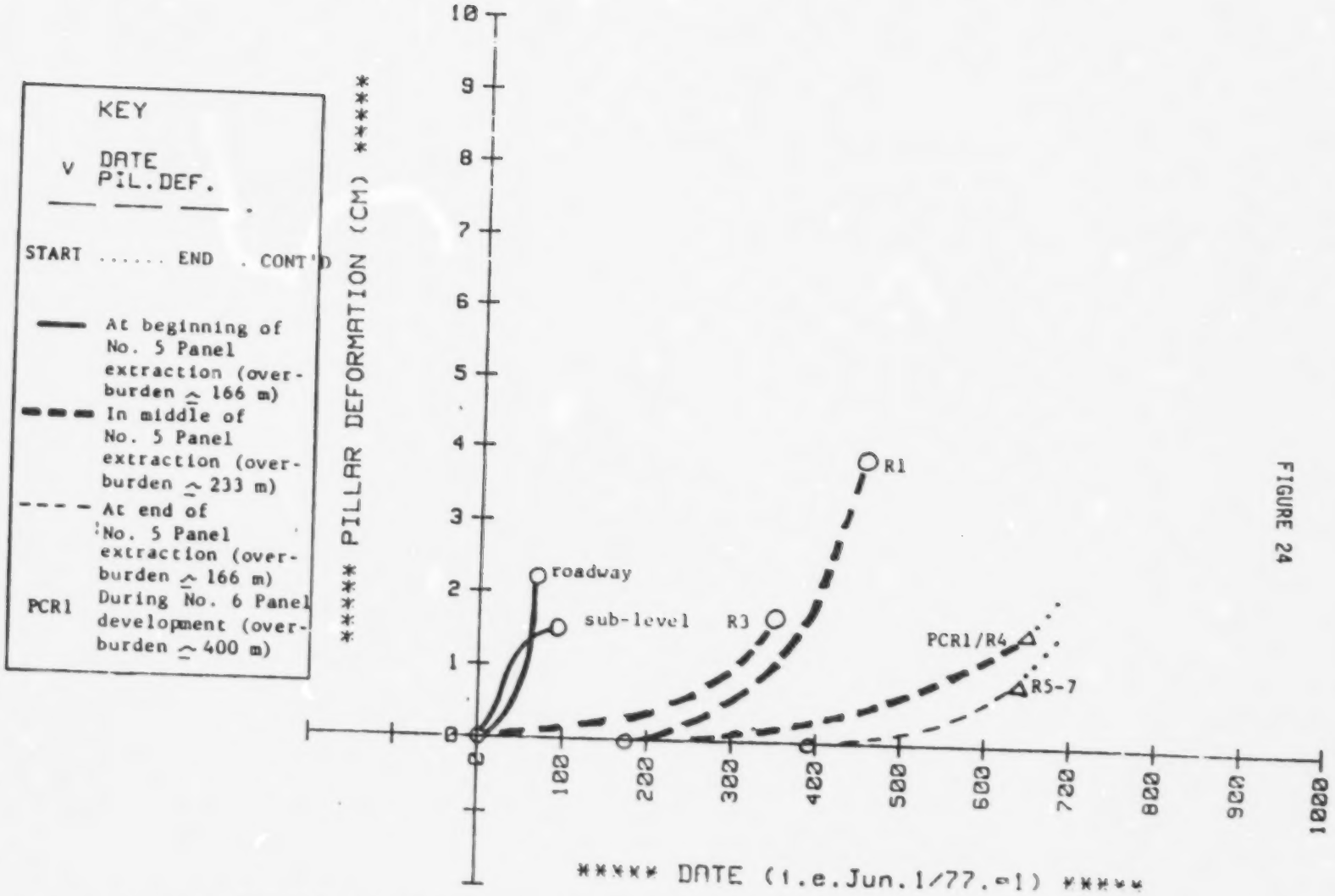


FIGURE 24

Fig. 24 - RESULTS OF IN-SITU MEASUREMENT OF PILLAR DEFORMATION AT PANEL #5/6. KRL.&MRL.77-78.

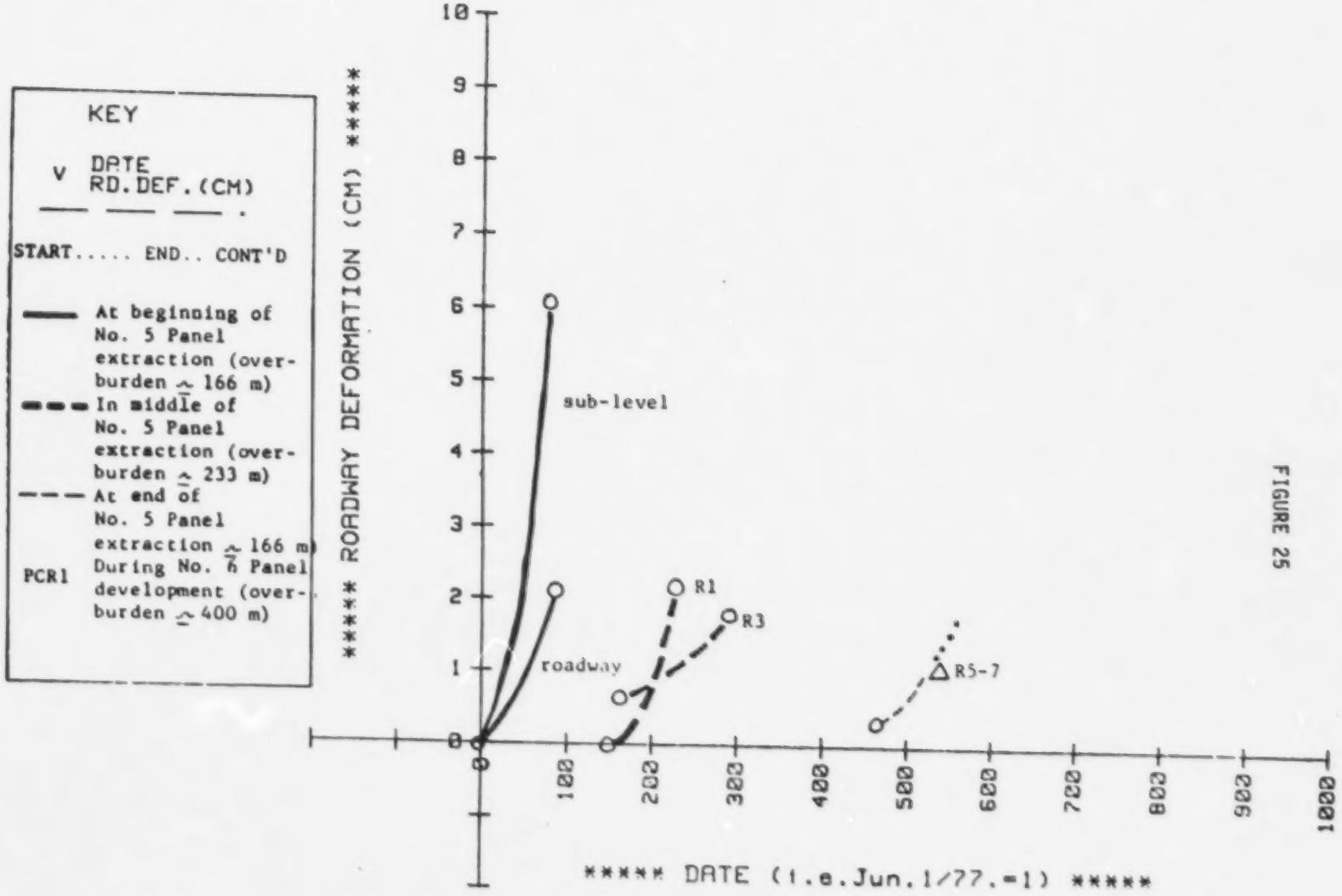

KEY
V DATE
RD. DEF. (CM)
START..... END.. CONT'D
At beginning of No. 5 Panel extraction (overburden ≃ 166 m)
In middle of No. 5 Panel extraction (overburden ≃ 233 m)
At end of No. 5 Panel extraction ≃ 166 m)
PCR1 During No. 5 Panel development (overburden ≃ 400 m)
***** ROADWAY DEFORMATION (CM) *****
sub-level
roadway
R1
R3
R5-7
***** DATE (i.e.Jun.1/77.=1) *****

FIGURE 25

Fig. 25-RESULTS OF IN-SITU MEASUREMENT OF ROADWAY DEFORMATION AT PANEL #5. KRL.&MRL.77-78.

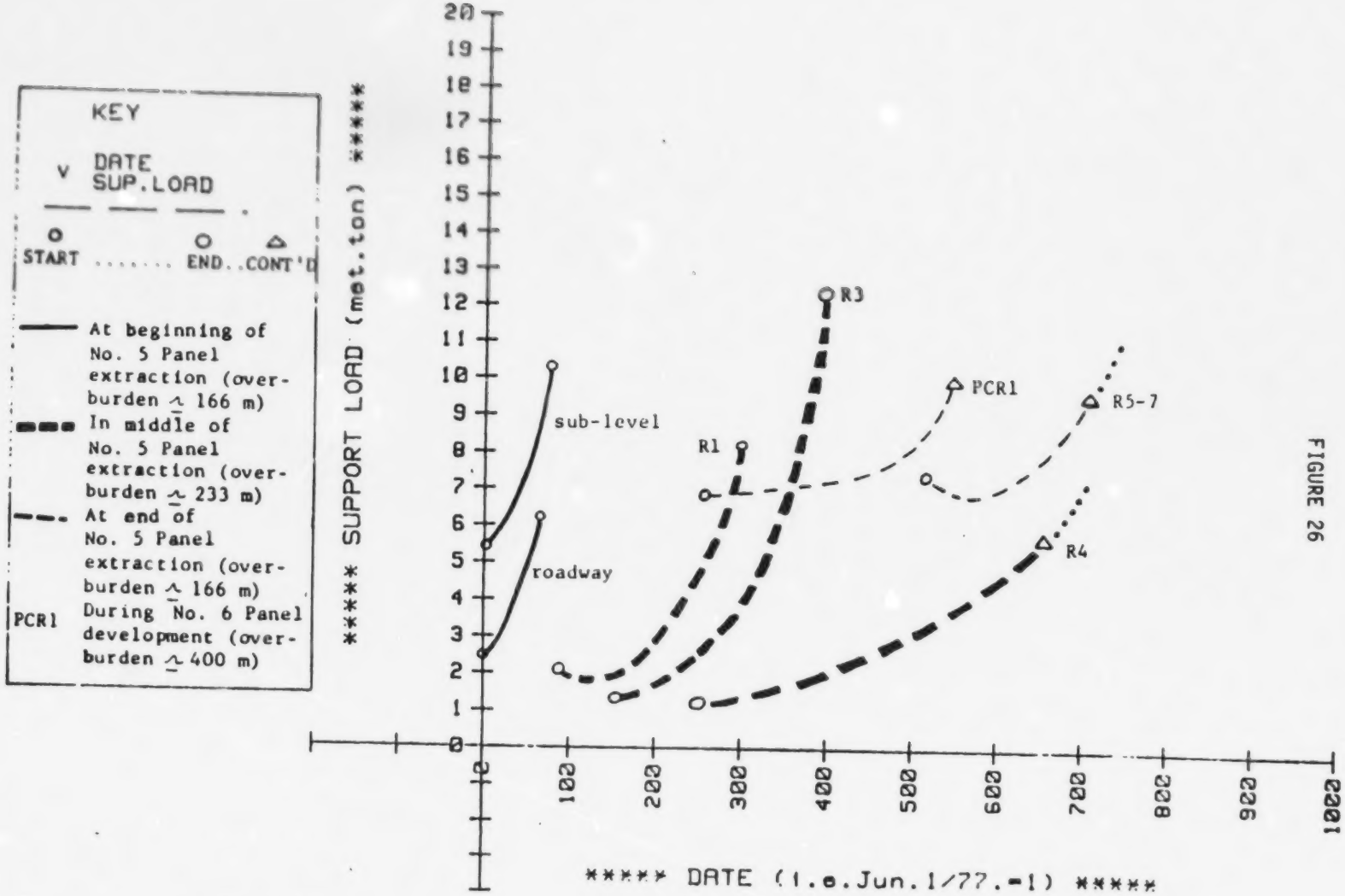


FIGURE 26

Fig. 26 - RESULTS OF IN-SITU MEASUREMENT OF SUPPORT LOAD AT PANEL #5/6. KRL. & MRL. 77-78.

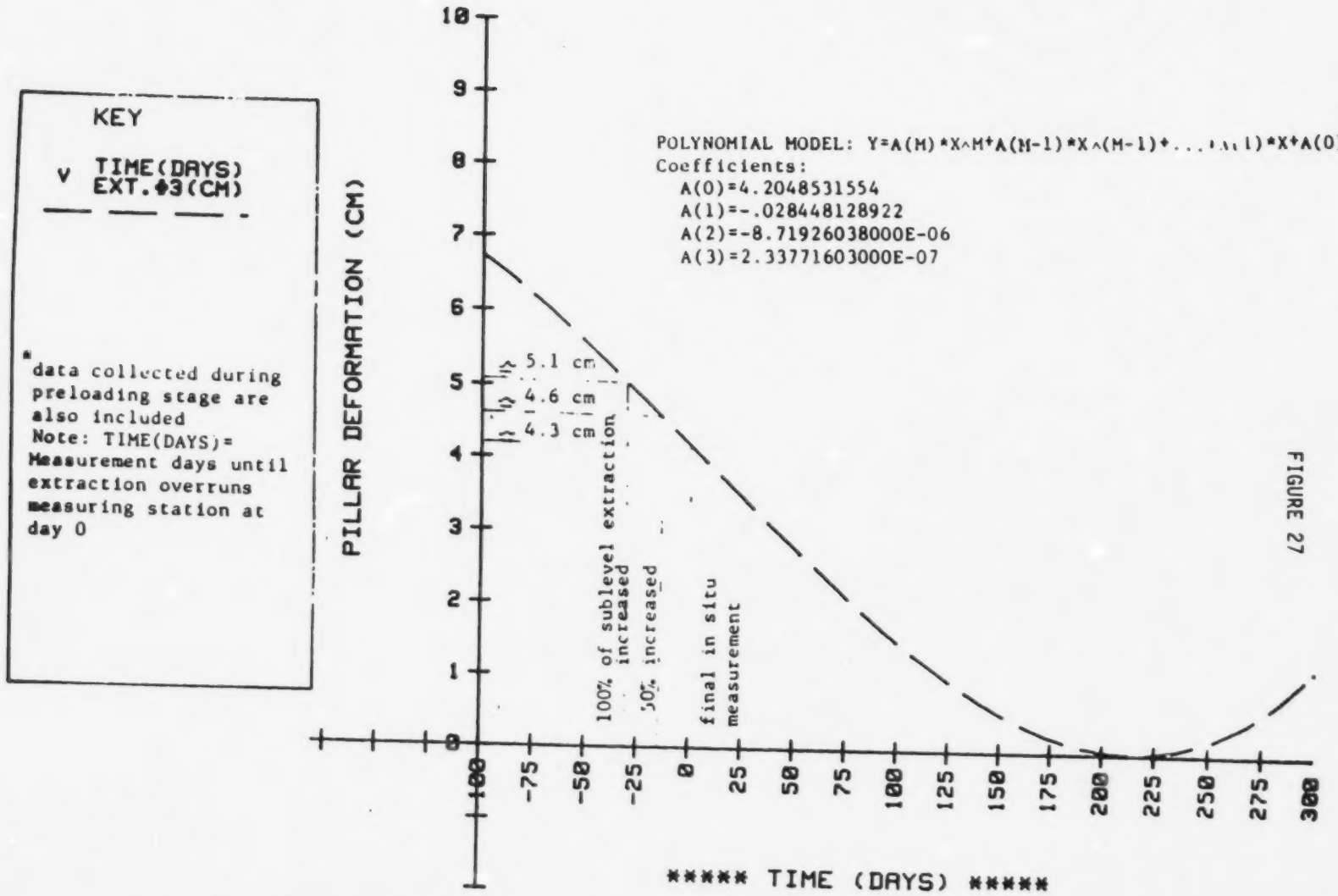


FIGURE 27

Fig. 27 - R1.PILLAR DEF.& TIME. #1 ENTRY.25-26 SUB. PANEL#5.
M.Y.F./C.C./W.B.....KRL. & MRL. 77-78.

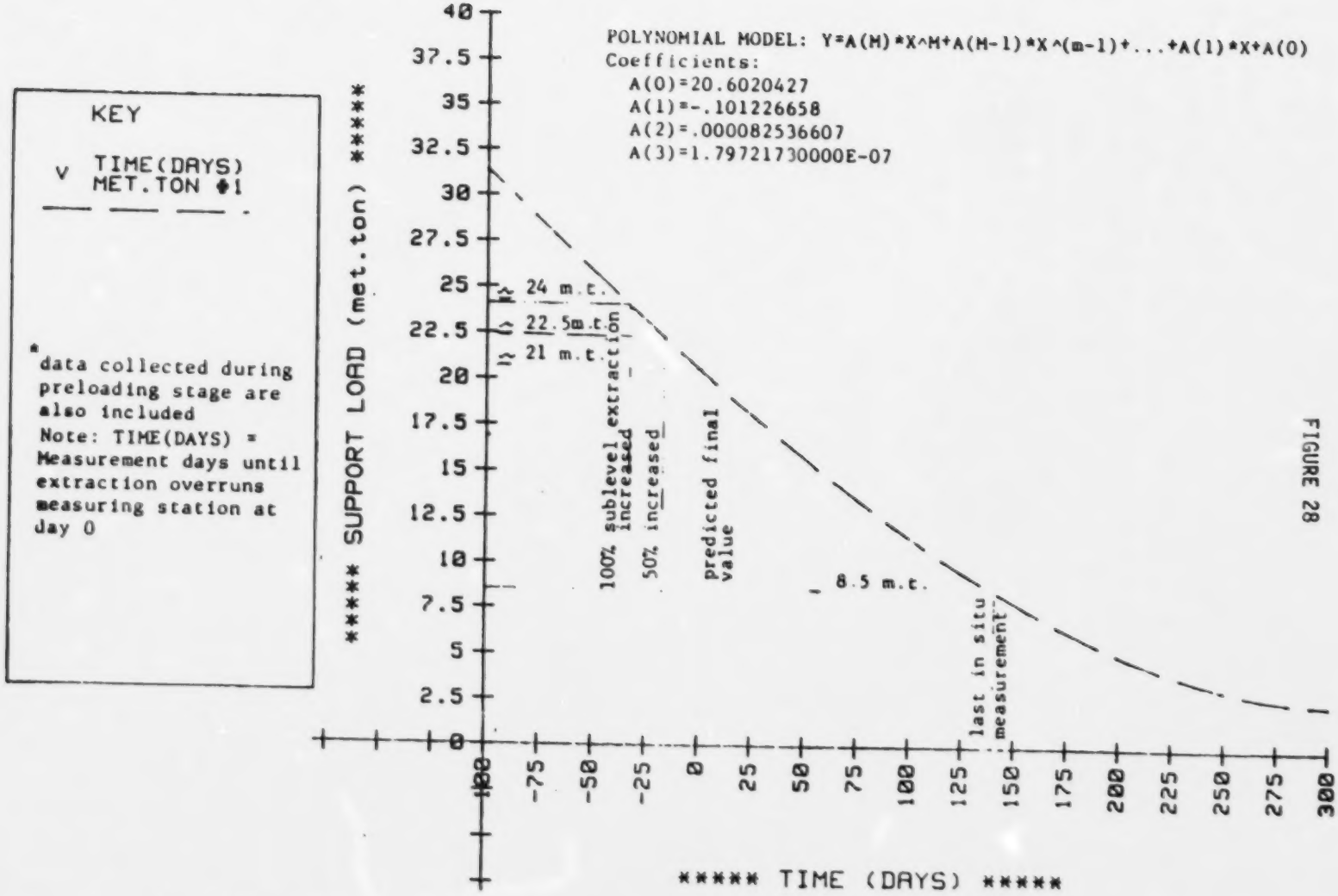


FIGURE 28

Fig. 28 - R!. SUPPORT LOAD & TIME. #1 ENTRY. 25-26 SUB. PANEL #5
M.Y.F./C.C./W.B.....KRL. & MRL. 77-78.

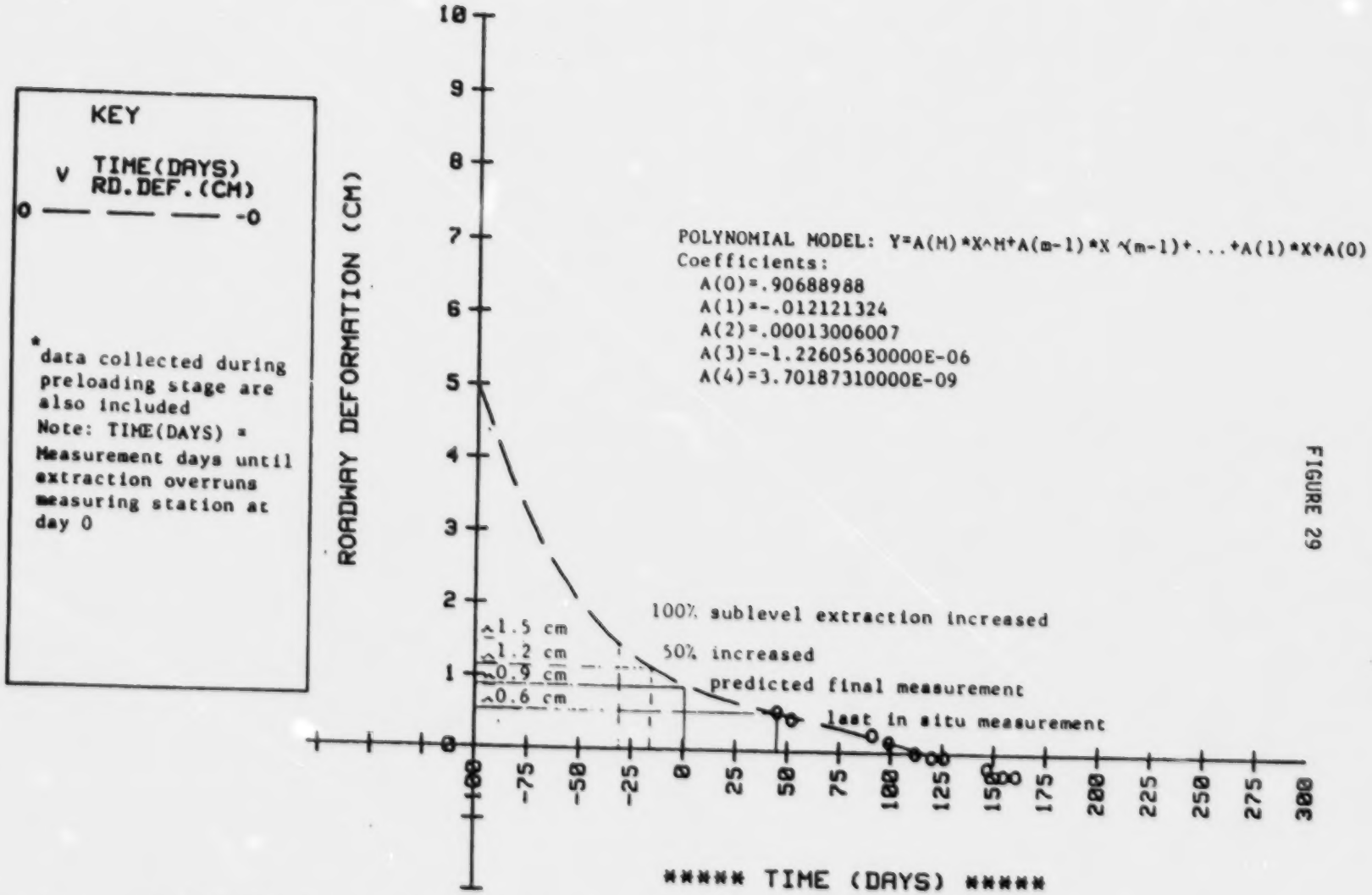


FIGURE 29

Fig. 29 - R3. ROADWAY DEFORMATION & TIME....26 SUB. PANEL #5.
M.Y.F./C.C./W.B.....KRL. & MRL. 77-78.

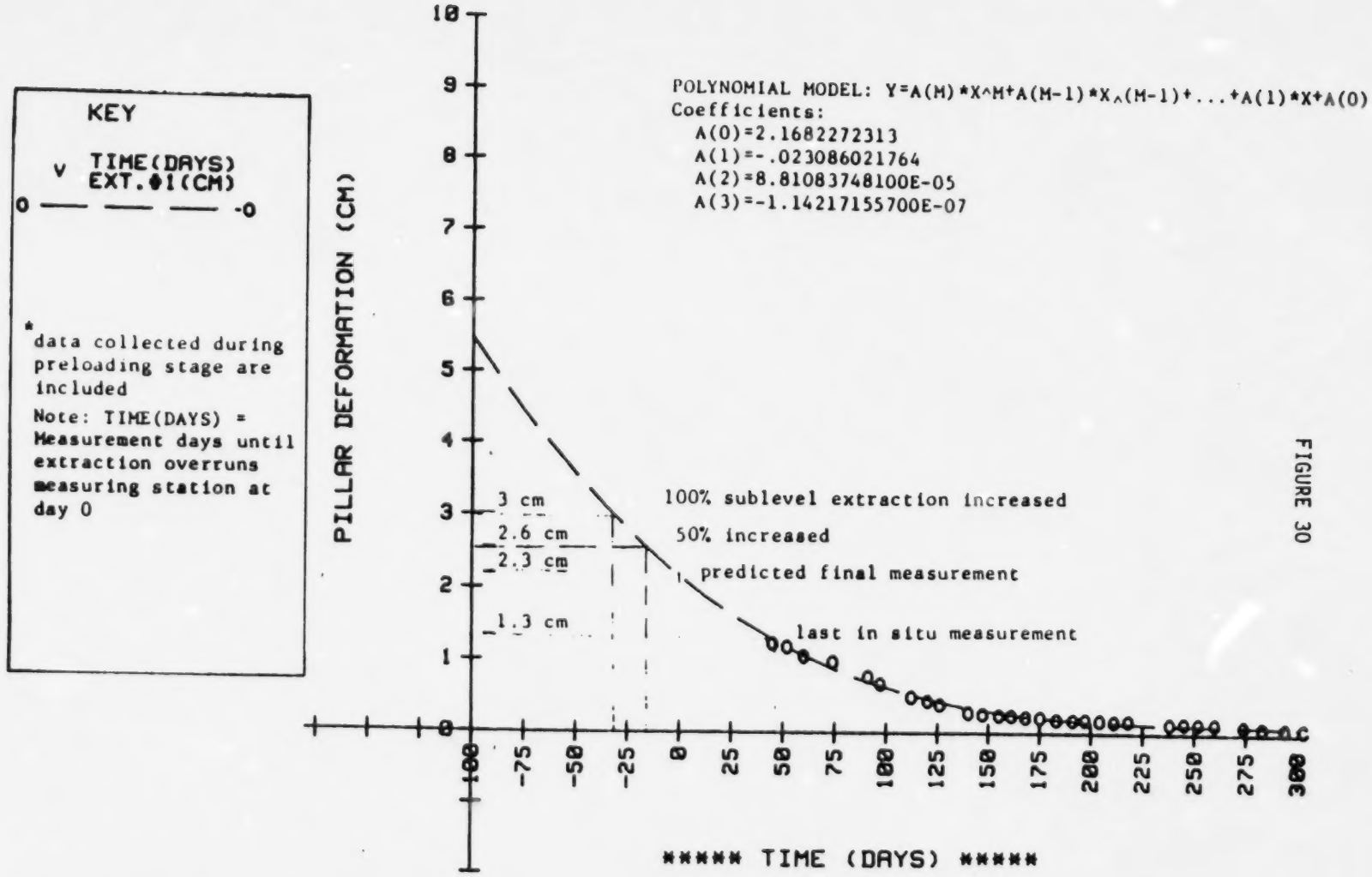


FIGURE 30

Fig. 30 - R3.PILLAR DEFORMATION & TIME. 26 SUB. PANEL #5.
M.Y.F./C.C./W.B.....KRL. & MRL. 77-78.

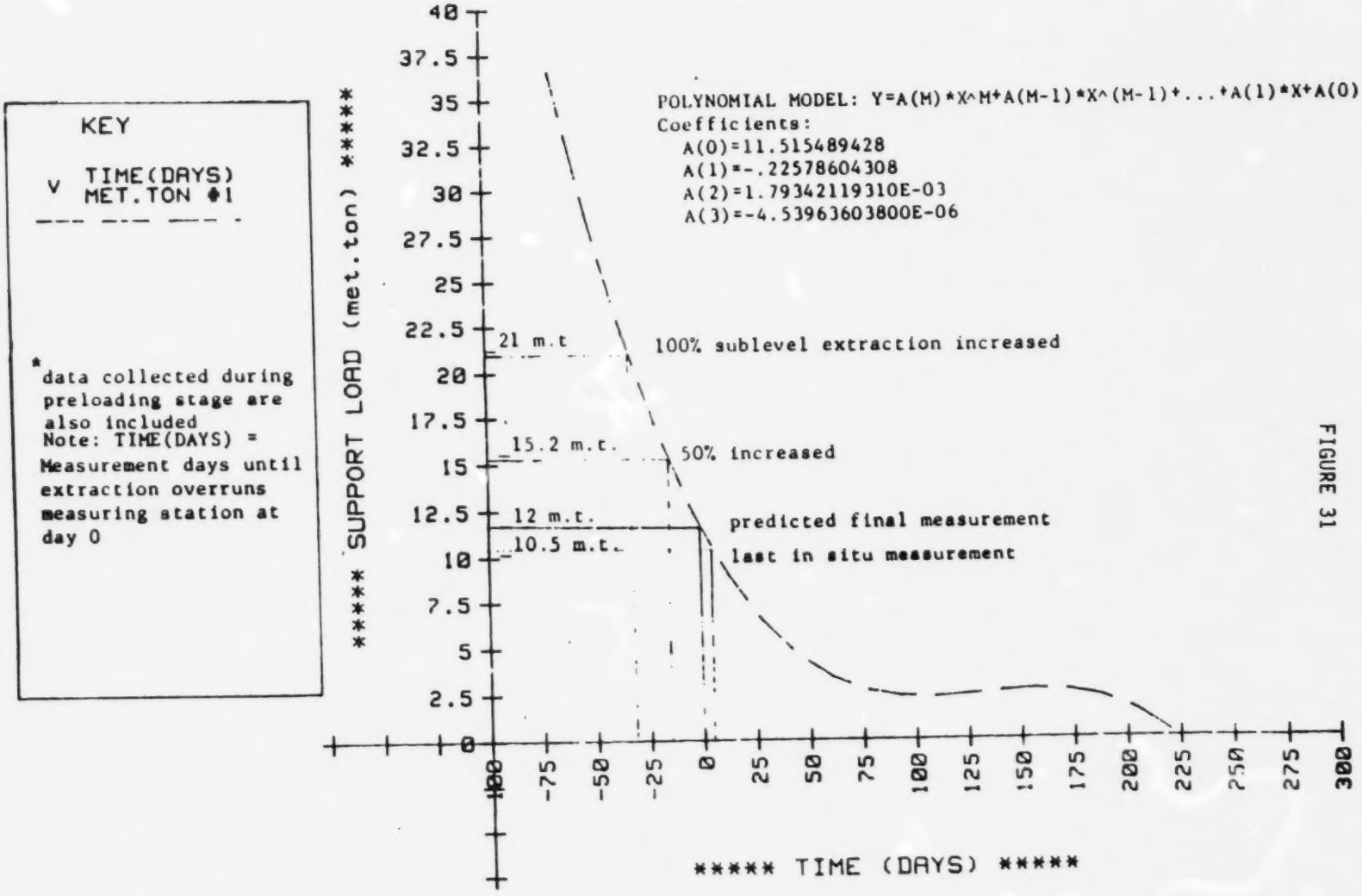


FIGURE 31

Fig. 31 - R3.SUPPORT LOAD & TIME.....26 SUB.PANEL#5.KRL.
M.Y.F./C.C./W.B.....KRL. & MRL. 77-78.

station to the monitor R1 and 23mm at the main road. Other stations indicated maximum values of 50 and 35mm. The absolute movement of roof to floor which had been determined by the convergence station, was approximately 35mm after 70 days of extraction; also at the same position and over time period, the survey showed a roof lowering of just over 30mm.

The results of strata movement measured by multi-wire extensiometers at stations R1 and R2 show a change in strata movements of the order of 17.3mm at a total depth of 36m above the sub-level and of 21.5mm at a depth of 6m below the sub-level. It was apparent from the preliminary analysis of measurements that these movements only occurred in the buttress zone of the sub-level. In other words, it was within the coal rather than in the rock strata above or below. In fact, these measurements correspond well with the total roadway convergence measurement at the same location, which was 45mm.

The results from pillar-deformation measurements confirm the view expressed above, that a small amount of displacement occurred during the operations in the sub-level. Even though these values are small, it was found that the displacements increased with distance, as discussed below. The results obtained in station No. R1 indicated negligible change, even though this was the closest station to the monitor on the rise side. On the other hand, in the same area, No. R6 station, which was installed for measurements between the sub-level and main road, indicated a gradual increase beginning at a point approximately 120m from the monitor and reaching a maximum value of 16.8mm when the monitor was 53m away from the station.

Further measurements revealed that there was no significant build-up of deformation and support load in active working areas, which indicated a de-stressed zone.

On the other hand the trend of the data collected seemed to indicate that the area of influence tends to be greatest 150-300 meters ahead of the face (Figure 32). A possible explanation is that the cushion effect of the thick friable coal seam pushes the front abutment further over into the solid coal.

3.2 SURFACE

3.2.1 Preliminary Measurements

After surface movements were detected above the mined out area of Panel 4A in 1974, attempts were made to determine the nature and extent of these movements, and to arrange the measurement system before the 1974 snowfall.

The surface area was very rugged and covered with thick bush and trees. Therefore measurements of lateral movements were made by

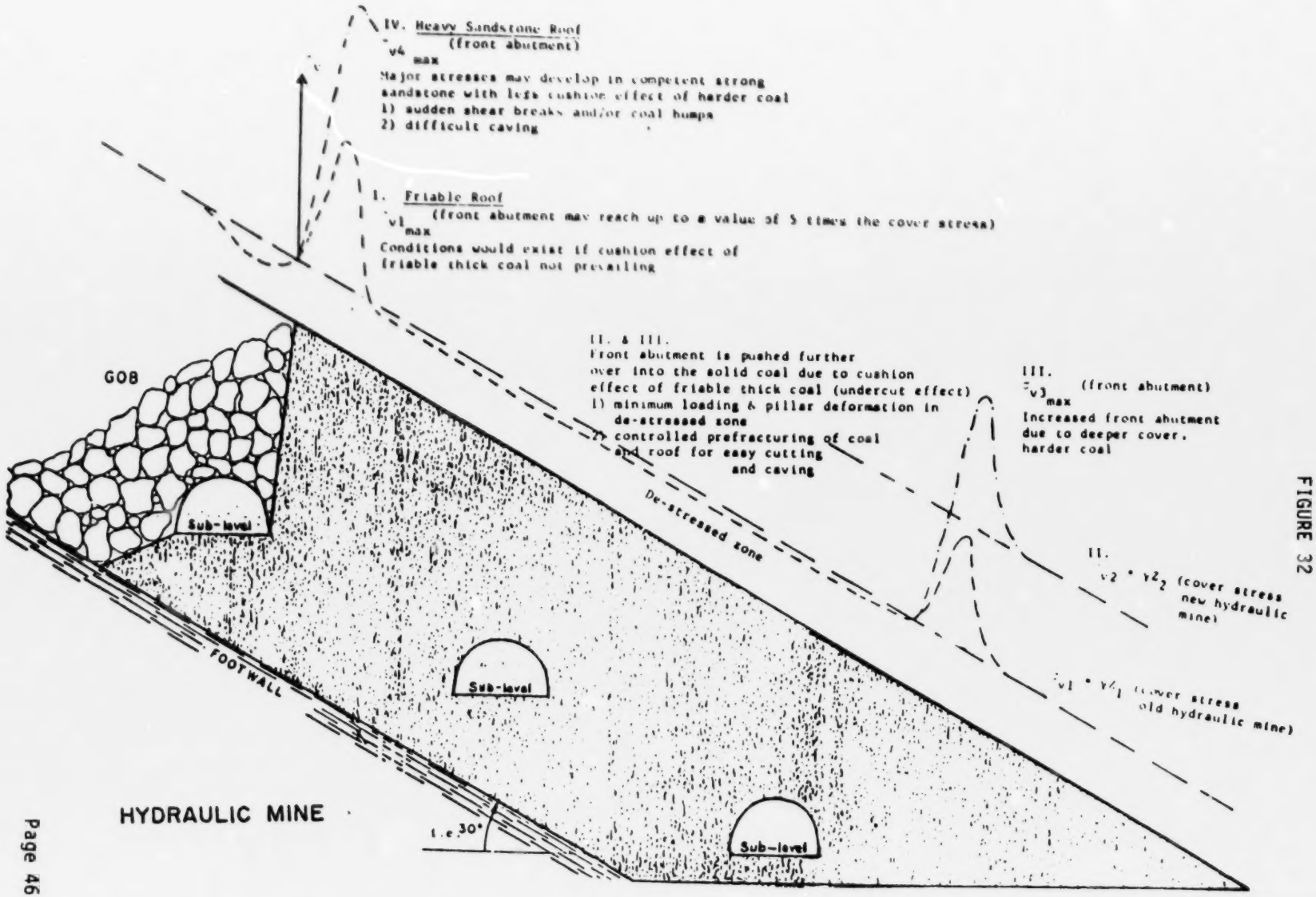

IV. Heavy Sandstone Roof
(front abutment)
Major stresses may develop in competent strong sandstone with less cushion effect of harder coal
1) sudden shear breaks and/or coal bumps
2) difficult caving
I. Friable Roof
(front abutment may reach up to a value of 5 times the cover stress)
Conditions would exist if cushion effect of friable thick coal not prevailing
II. & III.
Front abutment is pushed further over into the solid coal due to cushion effect of friable thick coal (undercut effect)
1) minimum loading & pillar deformation in de-stressed zone
2) controlled prefracturing of coal and roof for easy cutting and caving
III.
(front abutment)
Increased front abutment due to deeper cover, harder coal
II.
(cover stress new hydraulic mine)
(cover stress old hydraulic mine)
GOB
Sub-level
De-stressed zone
FOOTWALL
Sub-level
Sub-level
i.e 30°
HYDRAULIC MINE

FIGURE 32

FIGURE 32 - Possible Formation of Front Abutment in Thick and Steep Seam Mining

surveying tapes between the pins installed across cracks. Installation of an experimental electrical measurement system was successfully completed before the snowfall. This system consisted of a potentiometric extensiometer (designed by Dr. D. Hedley, Elliot Lake Laboratory) at the hill top, having a remote read-out unit beside the haul road 460 meters away. Measurement of displacement across a major fracture after the snowfall indicated that this instrument was functioning properly. Later attempts in winter to reach the remote read-out point were unsuccessful due to heavy snowfall on the haul road. Subsequent examination showed that the instrument was still functioning after the winter, but the measurement line between the cracks was broken due to differential movements of the ground. Laboratory investigations were carried out to develop an improved system to take these measurements.

Preliminary plans were drawn showing the subsidence over 4A panel. Figure 33 show the affected area of approximately 61 meters width and 180 meters length at the hill top (elevation 1770 meters) and extending down to the points 60-90 meters away from the outcrop (elevation 1680 meters).

The observations indicate that extraction of No. 4A panel appears to have resulted in surface subsidence in the form of cracks varying from 0 to 5 meters, and in steps appearing at random distances with throws of 0-0.6 meters (Figure 5). The limit angle, which is the angle of inclination from the horizontal of the line connecting the edge of the No. 4A workings and the edge of the subsidence area, is 75^{0} (Figure 34). Depth of cover varied from 250 meters at the hill top to 45 meters at the edge of the outcrop pillar.

It was difficult to determine the effect of time on subsidence since the surface disturbance was discovered after initial failure of the ground. Further surface investigations showed that there was no substantial change in measurements between the fall of 1974 and spring of 1975. This indicated that the ground over No. 4A panel appeared to have settled.

As a result of this preliminary work, some understanding of ground movement was obtained, but it was still difficult to draw any firm conclusions regarding relative movement between panels. Although surface subsidence was relatively simple to measure, compared to the measurements of strata movements in the mine, careful analysis of a sufficiently wide range of subsidence observations was believed to be necessary before movements could be predicted with sufficient confidence.

On this basis, further research was felt necessary to study the following research aspects:

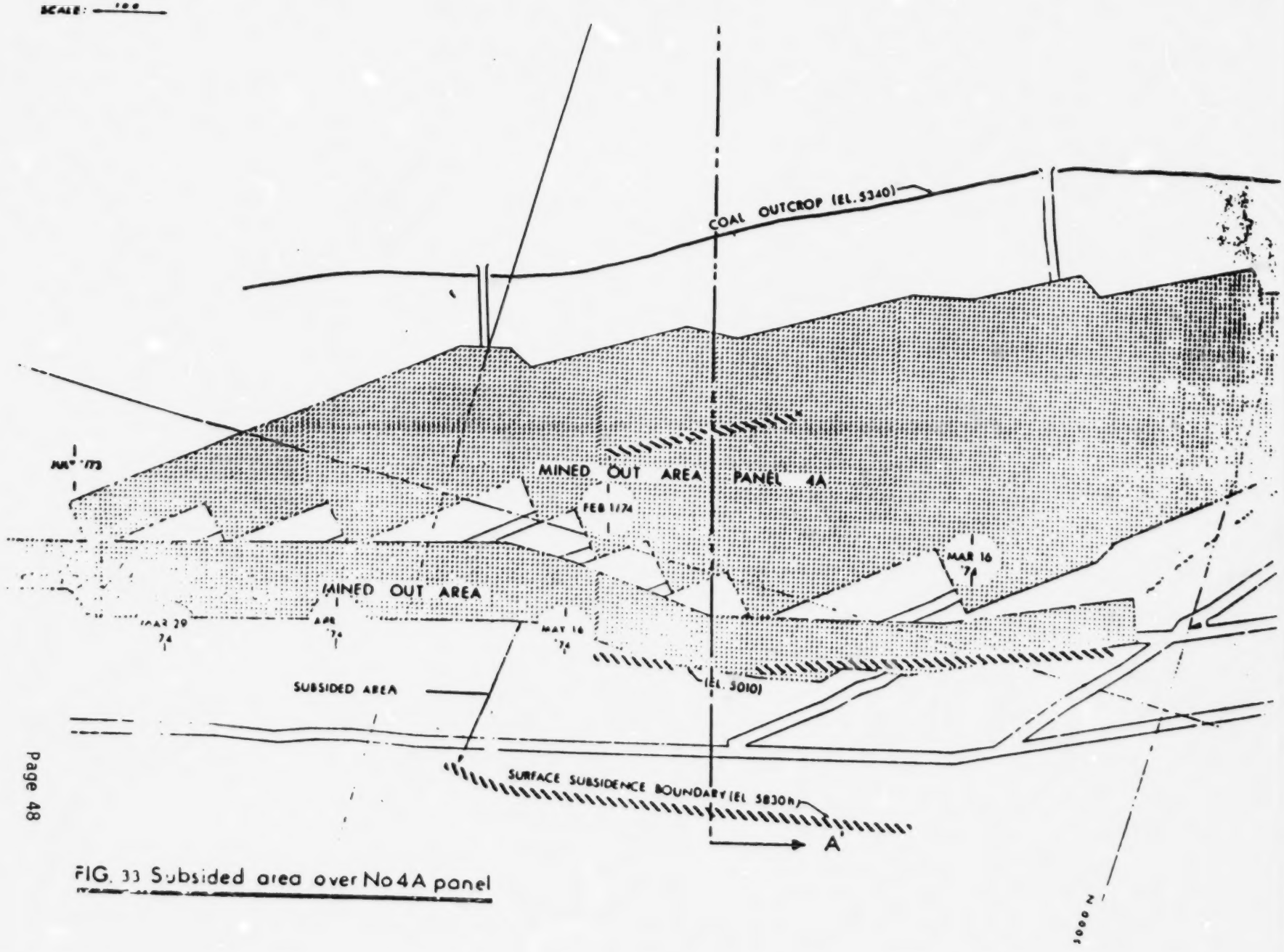


FIG. 33 Subsided area over No 4A panel

FIGURE 34

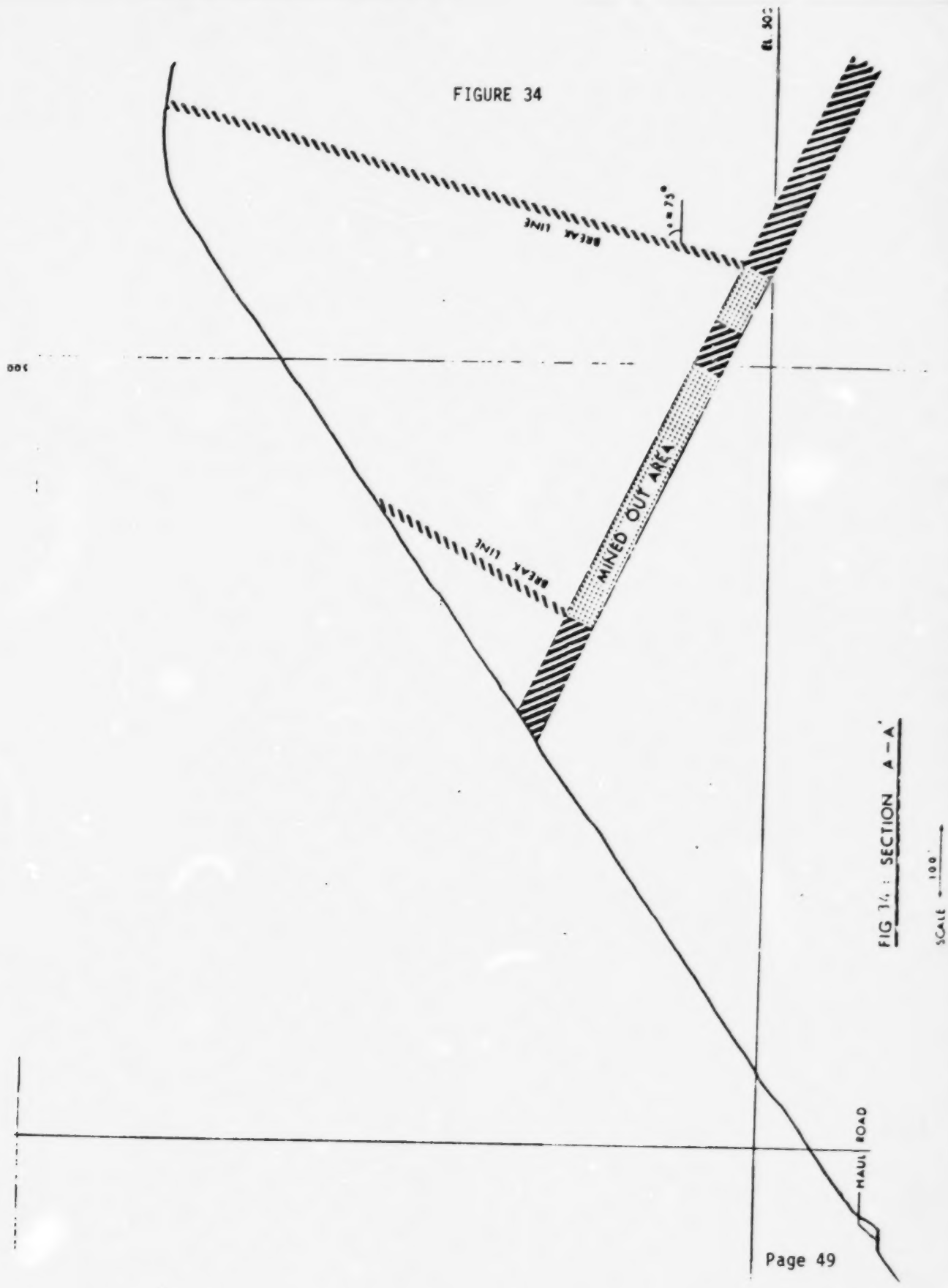


FIG 34 : SECTION A-A'

SCALE - 100'

1) Investigation of surface measurement techniques during winter months to determine progressive movements during underground extraction.

2) Determination of the limits of surface movement, maximum possible subsidence and the time-subsidence relationship over steep and rugged topography.

3) Determination, as far as possible, of the influence of pillars and of different geological conditions on subsidence.

4) Determination of extent to which results of European R&D subsidence engineering are applicable in Canadian coalfields.

3.2.2 Initial Method

Research work was organized to meet the requirement of surface studies, i.e. instrumentation and installation above present extracted areas and planned future workings.

The main objective was to define the lateral limits and vertical displacement that was developed by the extraction of underground panels, initially using instruments then available, and surveying services provided by the company, and to arrange these measurement areas where one could develop precise measurement techniques capable of operating within the extremes of a Canadian winter.

The initial problem was to establish the base line for surveying on the top of the hills above the newly developed areas, with the possibility of extending to future extraction panels. The steep pitch topography necessitated the use of four sub-stations for each surveying line, A and B (Figures 35 and 36), to cover the slope movements from the outcrop to the hill top.

The movements of the ground surface had been determined by periodic elevation surveys to fixed points in the area under observation. Two major stations to which all the successive elevations could be referred were therefore essential prerequisites, and these stations had to be located at the haul road for possible winter surveying and at the hill top well removed from the area affected by the surface movements. Surveying measurements had to be made on a weekly basis while the mining was in progress beneath the "Line A" and "Line B", but the time interval was later extended to a month.

The equipment employed in these surface subsidence surveys was an engineering theodolite (Wild T1A), reading directly to 20 sec and estimated to 5 sec of arc both horizontally and vertically. The surveying procedure is given below.

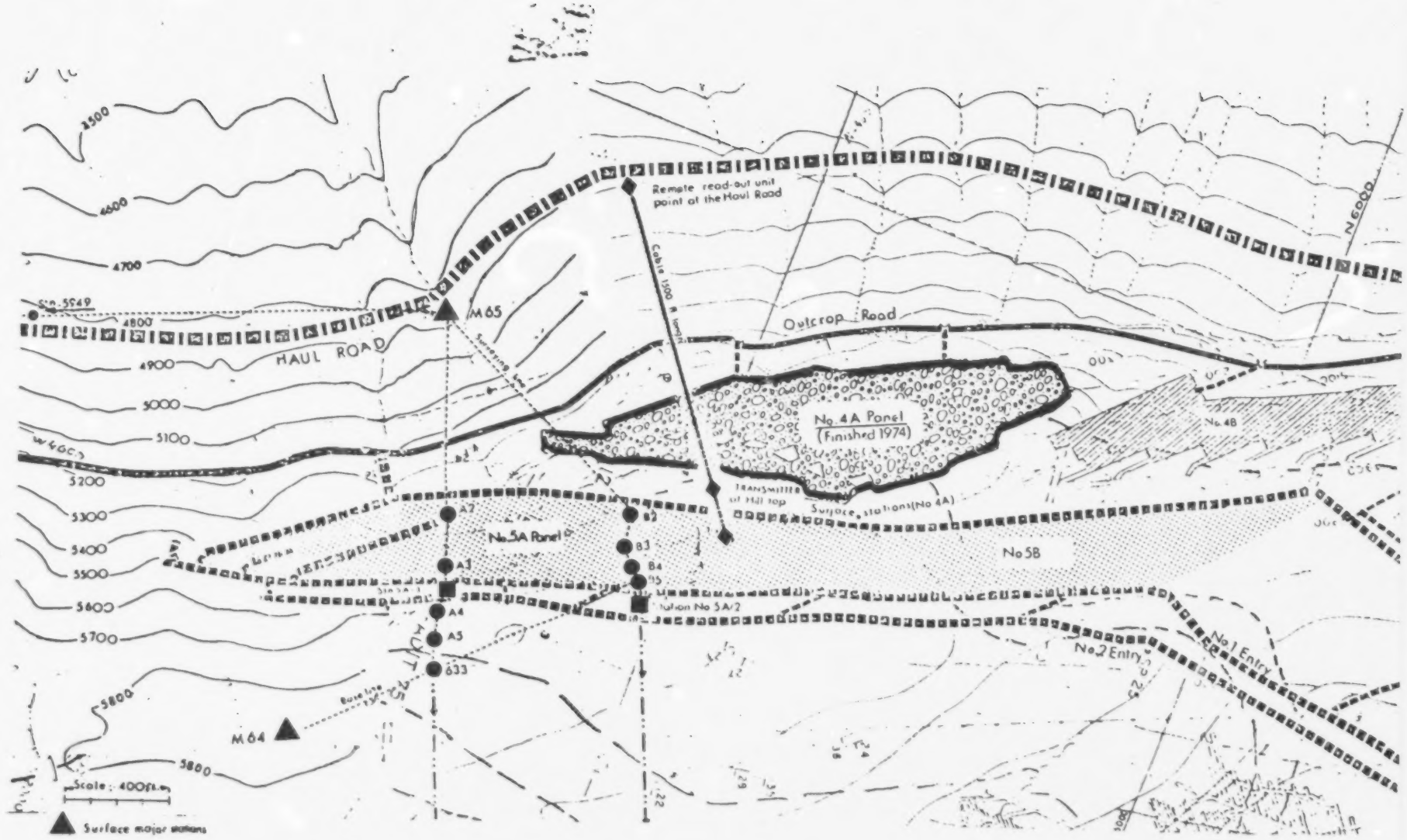


FIGURE 35 Hydraulic mine plan showing surface and underground strata control instrument stations together with surface contours.

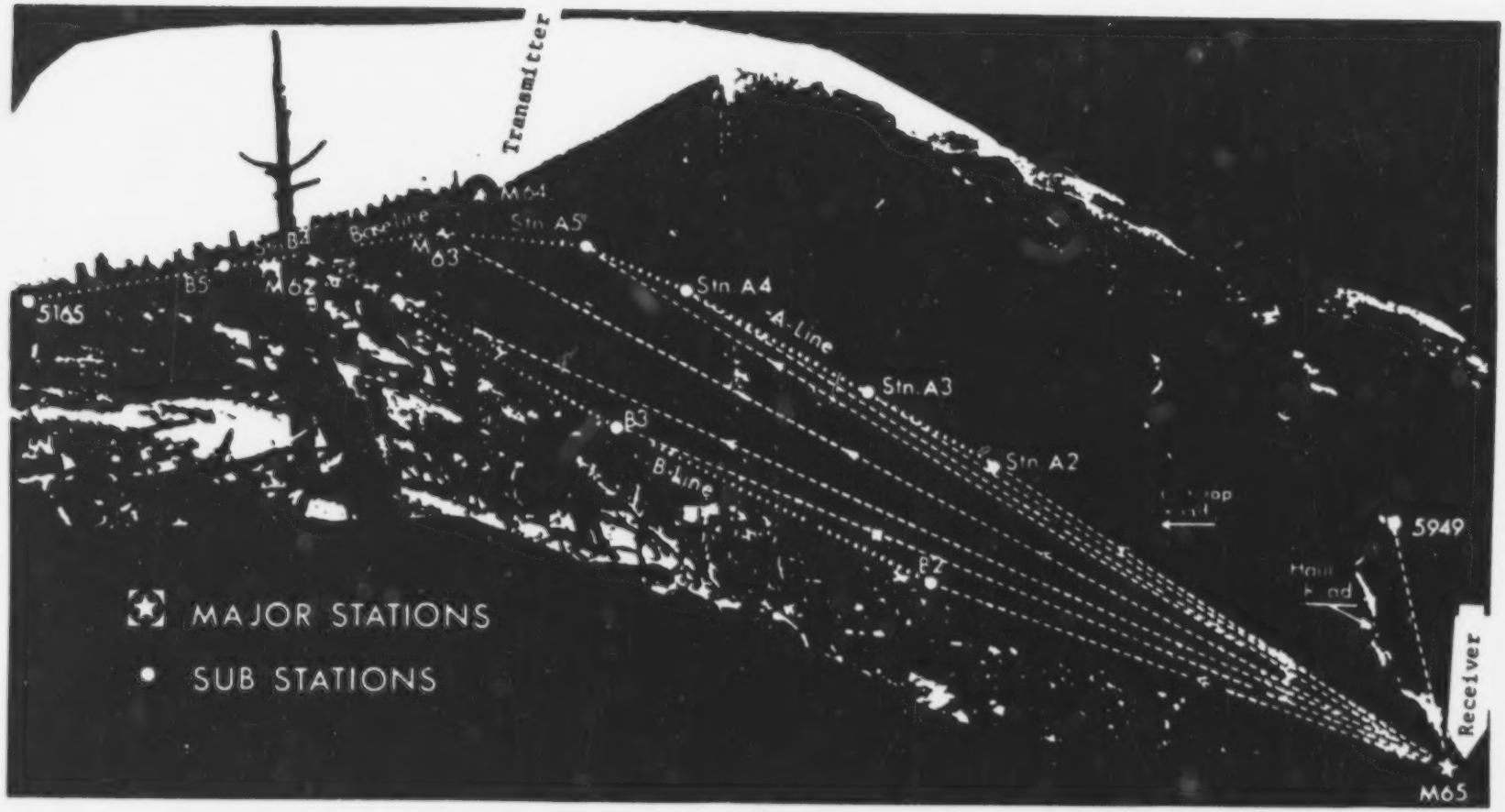


FIGURE 36 : Surface topography and subsidence stations over the hydraulic mine (No. 5A Panel)

1) Measured M62 - M63;
2) Triangulated M62 - M63 - M65;
3) Traversed from M62 down "B" line;
4) Traversed from M63 down "A" line;
5) Using co-ordinate so obtained plus co-ordinate of M65, distances M65 - B4, M65 - B3, etc. were calculated.
6) Hence by taking vertical angles from M65 to each of the subsidence stations and knowing the horizontal distance between, the differences in elevation were calculated.

A number of measuring systems were then tested. However, the need for electro-optical equipment (laser or infra-red) became more evident, to further increase the accuracy and capability of measurement during winter months.

At that time the Electronic Distance Measurement instrument with an accuracy of $\pm$2 cm was chosen as Westar's primary method of measurement. This, combined with the installation of robust reflector targets in areas in line of sight to fixed permanent stations, continued to provide readings of subsidence until the mine closed in early 1985.

3.2.3 Telemetry

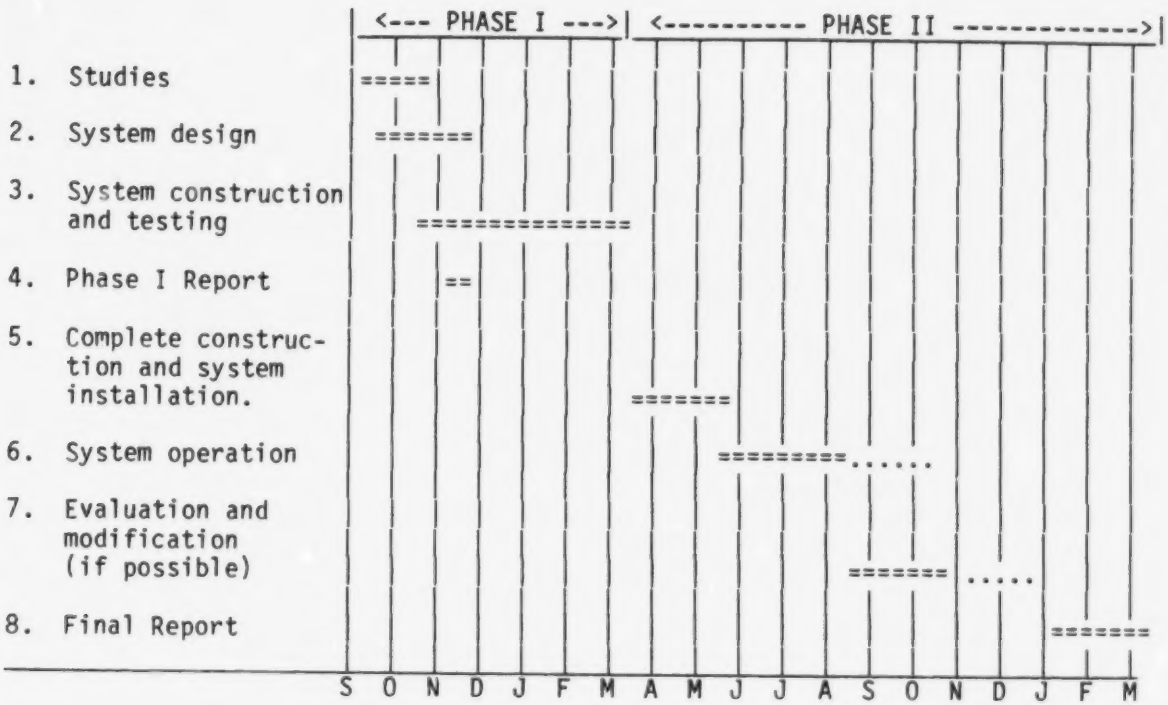
On March 30th 1979, a contract was awarded by CANMET to Ecological and Resources Consultants Limited (E.R.C.), Fredericton, to conduct a comprehensive study of subsidence measurement and telemetry systems for use in a coal mining area near Sparwood, B.C.

As early as 1977, a prototype radio transmitting system for remote recording of surface movement was installed to essentially determine the performance of the instrument during the winter months. The most important feature of this type of instrumentation was that the radio signals from several units at the surface could be transmitted to one radio receiver in an office, where data could be simultaneously recorded and processed on an hourly, daily or weekly basis.

The E.R.C. contract was divided into two phases, as shown below, spread over an 18 month period.

E.R.C. PROJECT SCHEDULE

Work Component


<--- PHASE I --->
<---------- PHASE II ---------->
1. Studies
2. System design
3. System construction and testing
4. Phase I Report
5. Complete construction and system installation.
6. System operation
7. Evaluation and modification (if possible)
8. Final Report
S O N D J F M A M J J A S O N D J F M

3.2.3 (a) Phase I of the Contract:

i) Conduct a comprehensive study of subsidence measurement and telemetry systems and photogrammetry technology that have or may be applied to the mining conditions in relevant mountain terrain (Sparwood Mountain, B.C.).

ii) Recommend systems for the field conditions below:

a) the slope angles to 45^{o}
b) temperature ranges -25^{o} to $40^{o}C$,
c) winter snow cover heavy, up to 5 metres,
d) surface cover consists of bush and trees on a thin sandy soil,
e) no access road to the proposed measurement site within 5 kilometres,
f) system must be capable of monitoring surface stations within a radius of 5000 metres at elevation differences up to 1000 metres.

iii) Design or adapt a prototype measurement/monitoring/telemetry system applicable to field conditions above.

iv) Prepare a report of Phase I which will include a reassessment of Phase II contract requirements and costs.

3.2.3 (b) Phase II was re-assessed after Phase I was concluded and consisted of:

i) Purchase of 5 tilt meters, slaves and master controller together with all mechanical and electronic components.

ii) Professional fees associated with procurement, calibration, field installation and testing, evaluation and reports.

All labour required during the installation of the tilt meter was supplied by Westar and included the telephone connections required by the master controller to the office computer.

Four tilt meters were installed over Panel 6100 in the area affected by Sub-levels 1 through 8 and were operational during most of the extraction period between 1980 and 1981, with subsequent measurements during most of 1982.

The system had operated with moderate success and was shown to be clearly sensitive to subsidence activity, providing a continuous record of measurements which were readily transmitted to Westar's underground operations office.

However, problems were initally encountered due to weather conditions and technical difficulties. Consequently, E.R.C. were continually upgrading the system which included improving radio transmission, computerized data correction and processing. In addition we noted that the overall complexity of the system would necessitate ongoing maintenance costs with the need for a locally based electronic technician suitably trained and available to Westar on a regular basis.

3.2.4 Aerial Photogrammetry

Part of the contract awarded to E.R.C. included in Phase I the "Investigation on the Application of Photogrammetry" which included both aerial and terrestial photogrammetry.

Terrestial photogrammetry was ruled out because the use of a special camera with an extremely large focal length would be economically unfeasible.

Aerial photography targets were placed over the ground surface and the area was flown over in October 1980. These ground targets were placed at uniformly spaced intervals over the study area and their locations determined by ground survey. The targets consisted of brightly painted sheets, each about one meter square, firmly pegged to the ground.

Subsequently, the area was flown over again in August 1981, September 1982, June 1983 and October 1984 at an elevation of about 1,000 meters above the ridge. At the same time, the position of

each of the ground targets was resurveyed providing reliable control data for use in photogrammetric interpretaton.

The resulting photographs, together with the ground survey information for the targets were then sent to E.R.C. for interpretation and analysis.

In the initial stages, ERC tried using conventional stereo plotting techniques to produce contour maps from each flight for comparison. However, they found that no meaningful trends of ground subsidence were distinguishable because the horizontal component of movement is substantial in this situation; a factor which is not compatible with the conventional method.

Consequently after reviewing subsequent flights, they proposed that the best method of analysis is to use a combination of photographs obtained from both flights to eliminate variable shadow patterns. This method appeared to give the highest accuracy when compared with ground survey measurements over the same period. Therefore, under the well controlled conditions, the horizontal and vertical movement of identifiable features in the time period between flights can be determined to an accuracy of $\pm$10cm. Contours of equal vertical displacement are shown on the transparent overlay on Figure 37.

3.2.5 Review of Surface Monitoring Results

In reviewing the results obtained during the 8 year study project, it must be recognized that some errors and inconsistencies were present due to the developmental nature of the program and the difficult terrain and severe climate of the study area.

The research program was initiated over Panel 4 and progressed southward to cover Panel 5 and 6, following the mining extraction progression.

The sequence of events in the period 1975 to 1983 is summarized on Table I and the results of the work are discussed in the following paragraphs. In 1983 Golder Associates were engaged by Westar Mining to review the geotechnical aspects of the mining operations. Some of their diagrams are used in this report.

The methods of surface subsidence fall into four main categories:

3.2.5 (i) Direct measurement of movement across cracks using tape measures and extensiometers;

Simple crack movement measurements made between the fall of 1974 and the summer of 1975 showed negligible change. The fact that mining of Panel 4A was completed at about the time that the monitoring work commenced may account, in part, for the absence of subsequent crack movement.

TABLE 1
SEQUENCE OF EVENTS
SURFACE SUBSIDENCE MONITORING PROGRAM
BALMER SOUTH MINE

DATE	AREA	WORK CARRIED OUT	COMMENTS
1974/5	Panel 4A	Surface cracking observed. Crack movement monitored.	Tape measures between pins. No movement detected, but mining already complete.
		Potentiometric extensiometer across cracks.	Technical difficulties. High vertical displacement makes method impractical.
1975-78	Panel 5A	Improved extensiometer 33m long.	Performed well in summer. Subsequent technical difficulties. Rejected as long term monitoring device.
		Ground survey of fixed targets monthly or bi-monthly.	See Figures 35 & 36 for target location and typical result.
1978-80	Research and Development	Development of tiltmeter system with telemetry initiated. Preliminary development took 1.5 years prior to field installation.	Work subcontracted to ERC.
1980-82	Panel 6100 Subs 1 - 8	Five tiltmeters installed August 1980.	Mining Panel 6100 starts April 1980. Results shown on Figure 42.
		Ground survey monitoring initiated using EDM methods.	Results shown on Figures 39, 40 and 41.
		Aerial photography carried out October 1980, August 1981, and September 1982.	Total surface subsidence contours shown on Figure 37.
1983	Panel 6100 a) Subs 1-8	Existing tiltmeters overhauled, 3 new tiltmeters being prepared.	Ready for installation June 1983 by ERC.

TABLE 1 - PAGE 2
SEQUENCE OF EVENTS
SURFACE SUBSIDENCE MONITORING PROGRAM
BALMER SOUTH MINE

DATE	AREA	WORK CARRIED OUT	COMMENTS
		Aerial photography, ground survey - report in preparation by CANMET (unofficial results reviewed by Golder Associates).	Due April 1983.
	b) Subs 17-21	Aerial photography in March 1983 with ground survey control.	Objective to demonstrate initiation of caving.
		Golder Associates review subsidence monitoring methods and recommend rational use in mine control of surface subsidence monitoring program.	Report due April 1983. Ongoing review of program during 1983.
	c) Subs 9 - 16	Westar Mining carry out surface subsidence monitoring.	Ongoing review during 1983.

Although the extensiometer itself functioned throughout the winter of 1974/75, snow prevented access to the readout unit, and subsequently wildlife destroyed the electrical cables. The absence of movements observed through simple crack measurement suggests that in fact the extensiometer would not have detected significant movement had it functioned through the winter.

Apart from the technical difficulties, the primary disadvantage of the extensiometer system was its inability to differentiate between horizontal and vertical components of displacement.

3.2.5 (ii) Ground survey monitoring of fixed surface targets using a total station electronic distance measuring device (EDM);

Panel 5A was mined out in 1975 and 1976. Surface subsidence was monitored using both ground survey and extensiometer methods. This work is described in the January, 1982 CANMET report.

Ground survey measurements of fixed targets were carried out on either a monthly or bi-monthly basis. The location of ground survey targets is shown on Figure 35, and the vertical displacements of two points against time and in relation to the sequence of extraction are plotted on Figure 38.

Although no major signs of surface distress were observed over Panel 5A during its extraction, Figure 38 demonstrates that significant ground surface subsidence occurred at point A4. In fact, the rate of vertical displacement appears to have increased abruptly during September 1976, subsequently decreasing during December, 1976. A total subsidence of about 1.5 meters was measured. By contrast, point B3 shows considerably less movement with no discernible abrupt response to panel extraction, as was detected at point A4.

In the case of points A4 and B3, significant movements were first detected when the roof span, measured down the dip line, was between 100 and 120m.

In the summer of 1980, extraction of Panel 6100 commenced. Ground survey targets were set up at the locations shown on Figure 37 along three section lines: "A", "B" and "1".

As coal extraction from subs 1 through 8 proceeded during 1980 and 1981, periodic ground surveys of the fixed targets were carried out using an EDM instrument. During the winter, some or all of the targets became obscured and a number of the targets were destroyed by natural causes. These measurements were continued until September 1982 in 6100, then subsequently in Panel 6200.

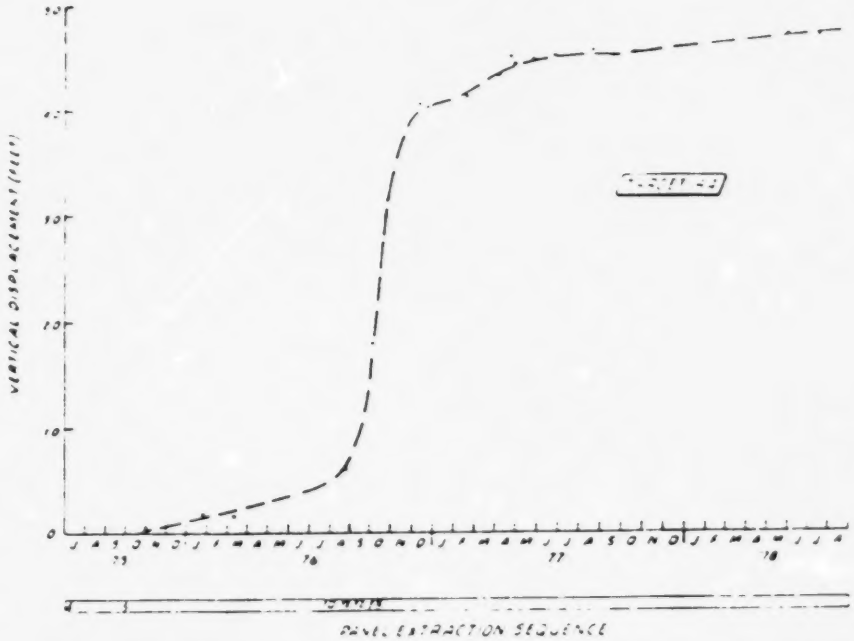
Figures 39, 40 and 41 present the results of the ground surveys of the fixed targets along section line A, B and 1, located as shown on Figure 37. It is noted that the frequency of surveys was irregular with only limited data available between the fall of 1980 and May of 1981.

BALMER SOUTH HYDRAULIC MINE
PANEL 6100 SUBS 1-8 LOCATION PLAN

Figure 37

PANEL 5 VERTICAL MOVEMENT OF GROUND SURVEY TARGETS

Figure 38



Note Location of targets A4 & B3 is shown on Fig 35

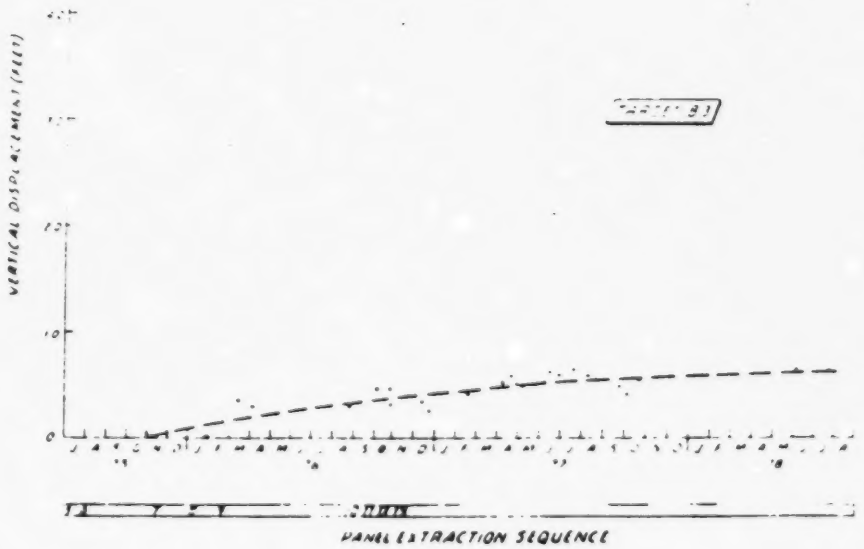


FIGURE 39

PANEL 6100 VERTICAL MOVEMENT LINE 'A'
(E.D.M. Ground Survey)

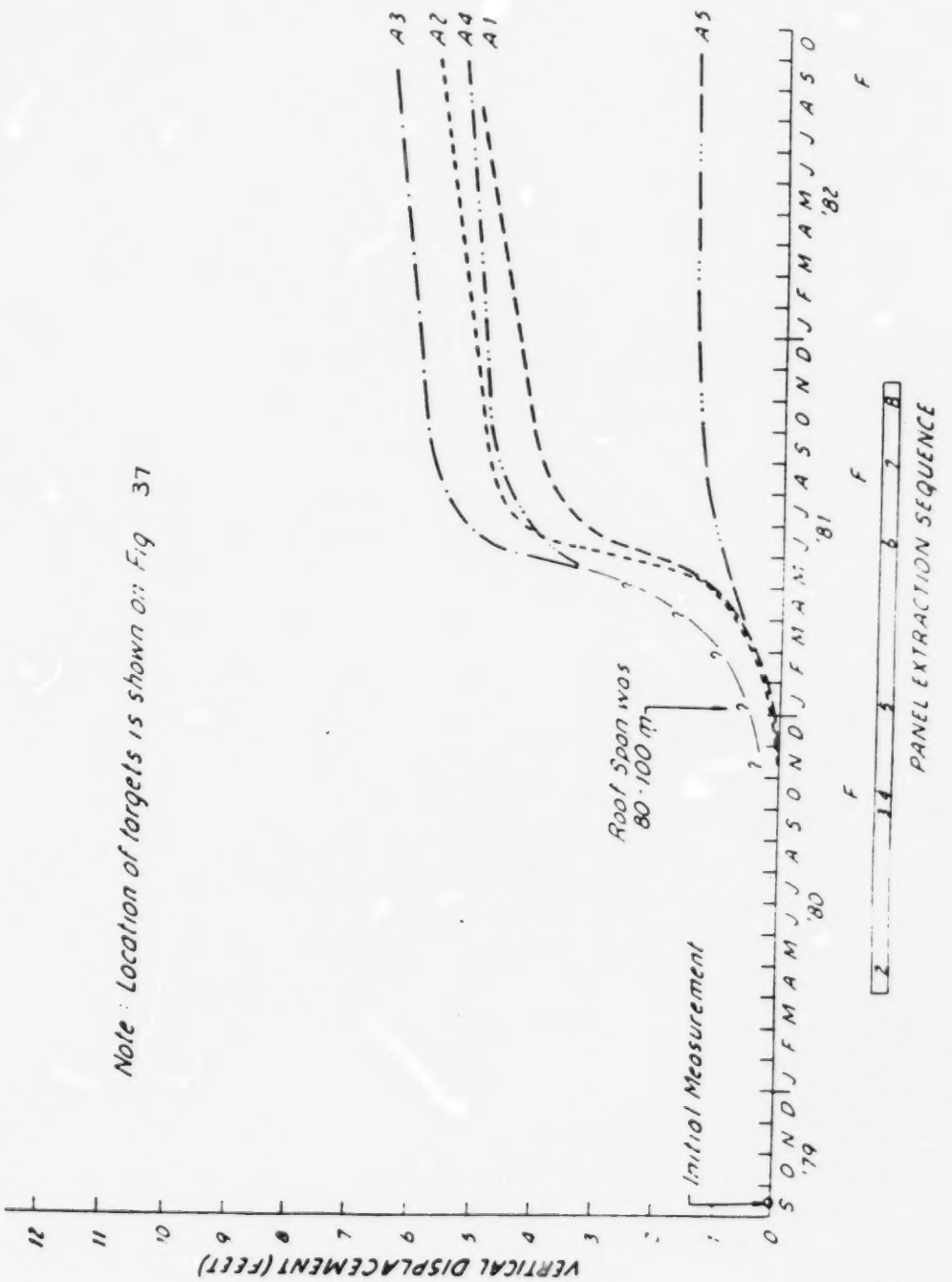


FIGURE 40

PANEL 6100 VERTICAL MOVEMENT LINE 'B'
(E.D.M. Ground Survey)

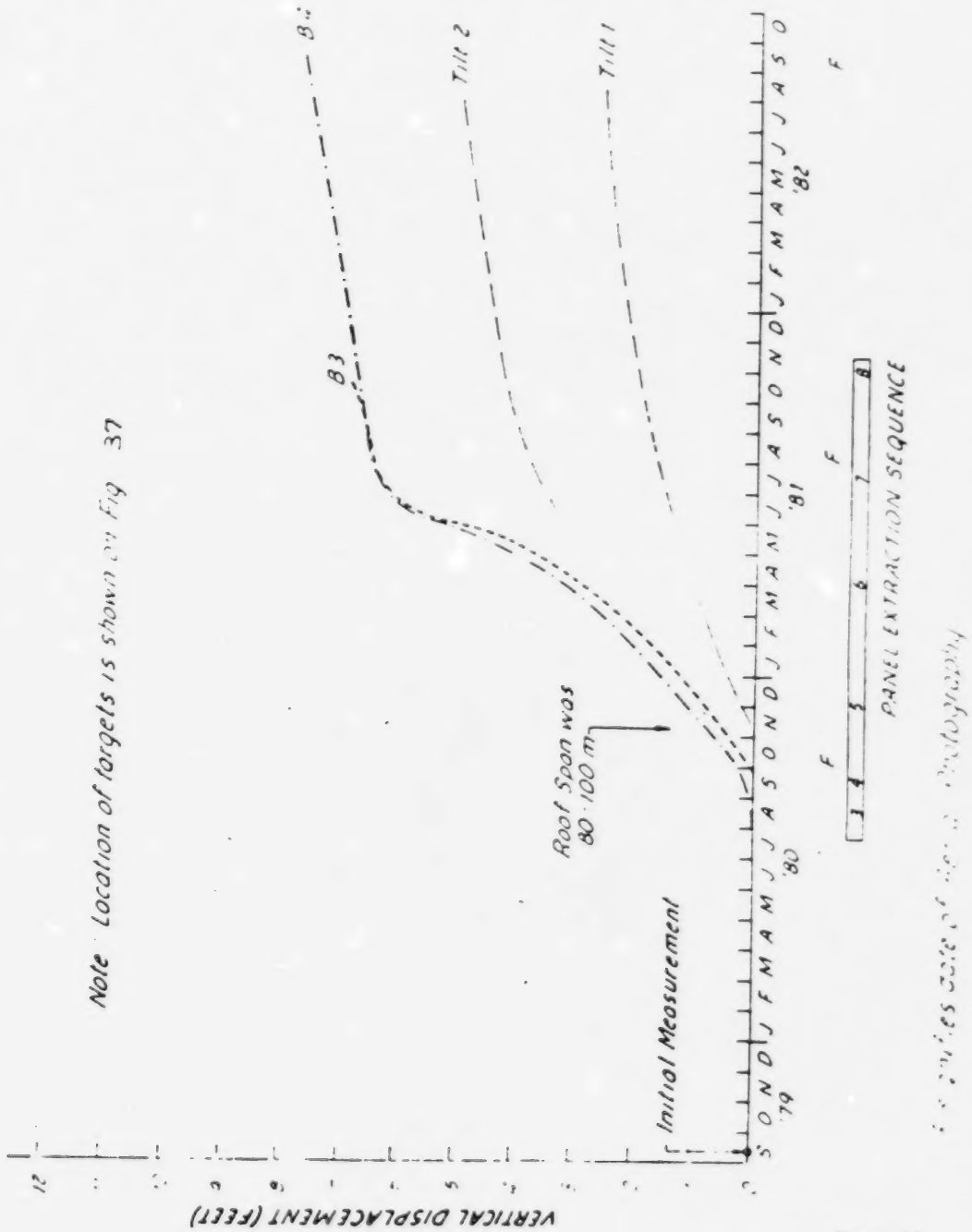
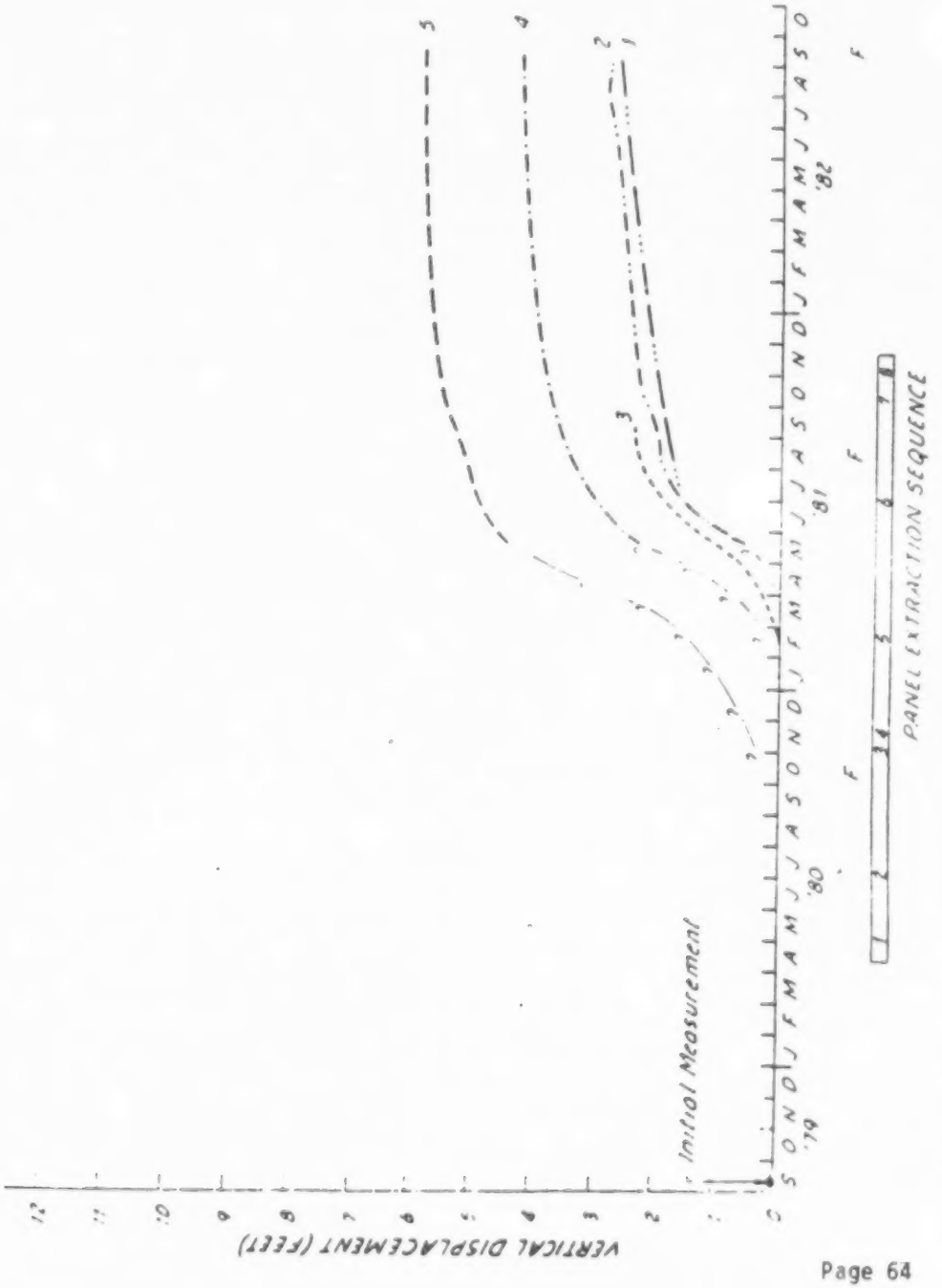

VERTICAL DISPLACEMENT (FEET)
S O N D J F M A M J J A S O N D J F M A M J J A S O
'79
'80
'81
'82
Initial Measurement
Roof Span was 80 100 m
PANEL EXTRACTION SEQUENCE
Note Location of targets is shown on Fig 37

FIGURE 41

PANEL 6100 VERTICAL MOVEMENT LINE '1'
(E.D.M. Ground Survey)



Along line A, significant movements were first detected during extraction of sub 5 when the roof span measured down the dip line would have varied between about 80 and 100m.

It can be clearly discerned that a significant increase in the rate of vertical subsidence occurred generally toward the end of extraction of sub 6 when the roof span would have been between 120 and 130m. This abrupt change occurred in late 1980 along section B, in late winter to early spring of 1981 along section A, and along line 1 in the summer of 1981. In all cases, the rate of subsidence decreased markedly again in July 1981, although extraction of subs 7 and 8 continued until the end of 1981.

Due to snow cover or poor weather, irregular monitoring of targets over this area did not permit a more detailed analysis of the data. However, after the installation of this system over panel 6200 and the necessary controls and regular monitoring procedures were in place, a caving front of high subsidence activity moved up and across the slope in response to progressing underground extraction.

3.2.5 (iii) Measurement of ground tilt at fixed locations by tiltmeters:

In the 1.5 year development period, various types of tiltmeters were examined and tested. A relatively inexpensive model was selected with the knowledge that careful calibration of each instrument would be necessary. This work was subcontracted to ERC who are specialists in the field of photogrammetry, surveying, and telemetry systems.

The overall accuracy of the system was found to be such that measurements of change in tilt exceeding 60 sec. of arc can be considered as significant.

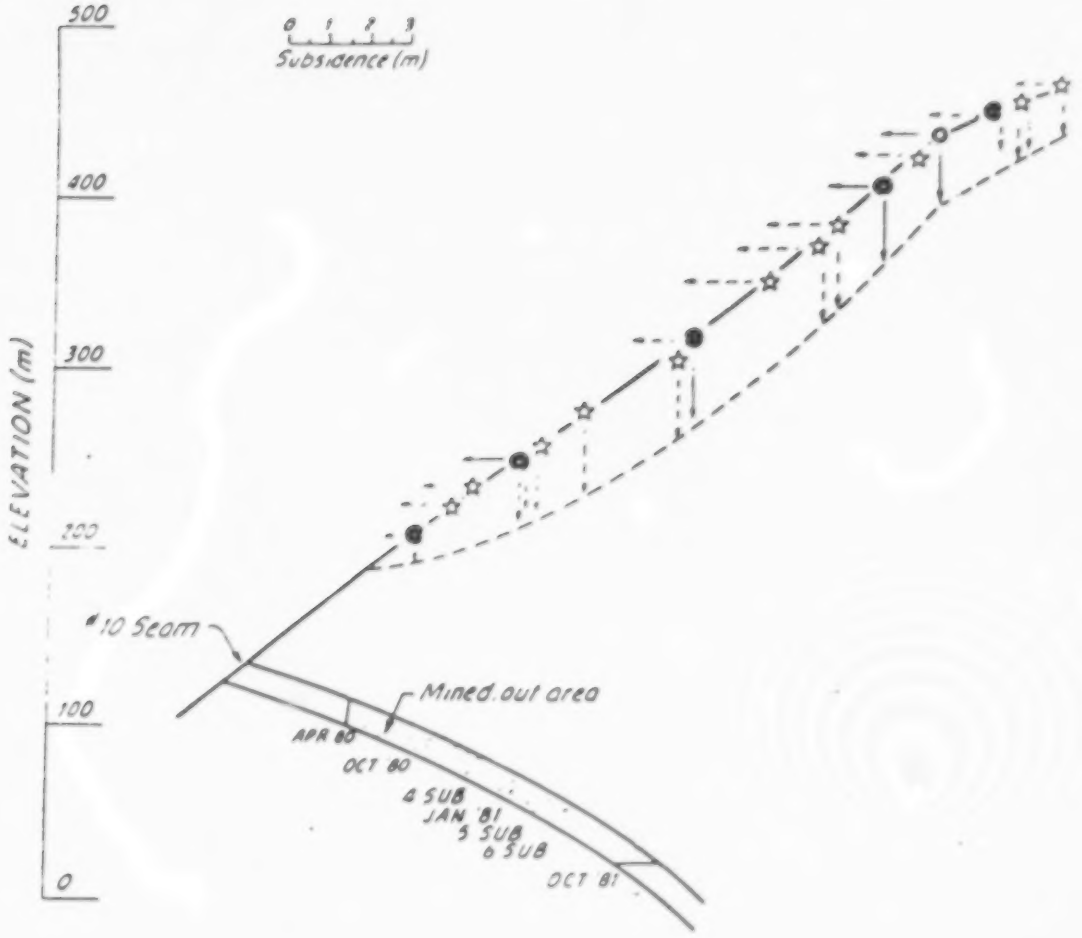
Figure 43 shows the recorded tilts at the four stations on Panel 6100, located as shown on Figure 37, over the period October 1980 to September 1982. This information was presented in the ERC monthly report for September 1982. The tiltmeter recordings covered the period October 1980 to September 1982, commencing after extraction had begun. Comparison with the results of ground survey work shown on Figures 39, 40 and 41 shows that a similar response was detected. Between October 1980 and April 1981, when subs 3, 4 and 5 were being extracted, a relatively low rate of tilt was detected. In marked contrast, between April and August 1981, a high rate of tilt of about 400 sec of arc per month was detected. This period corresponds approximately to the extraction of sub 6. After August 1981, up to cessation of monitoring in the fall of 1982, the rate of tilt decreased markedly to about 40 sec. of arc per month which represents a ten-fold change.

Detailed analysis and comparison of the results of tiltmeter recordings with ground survey data, in particular of the timing of

FIGURE 42

TYPICAL SECTION - PANEL 6100 MEASURED SURFACE MOVEMENT '80-'82

Figure 42



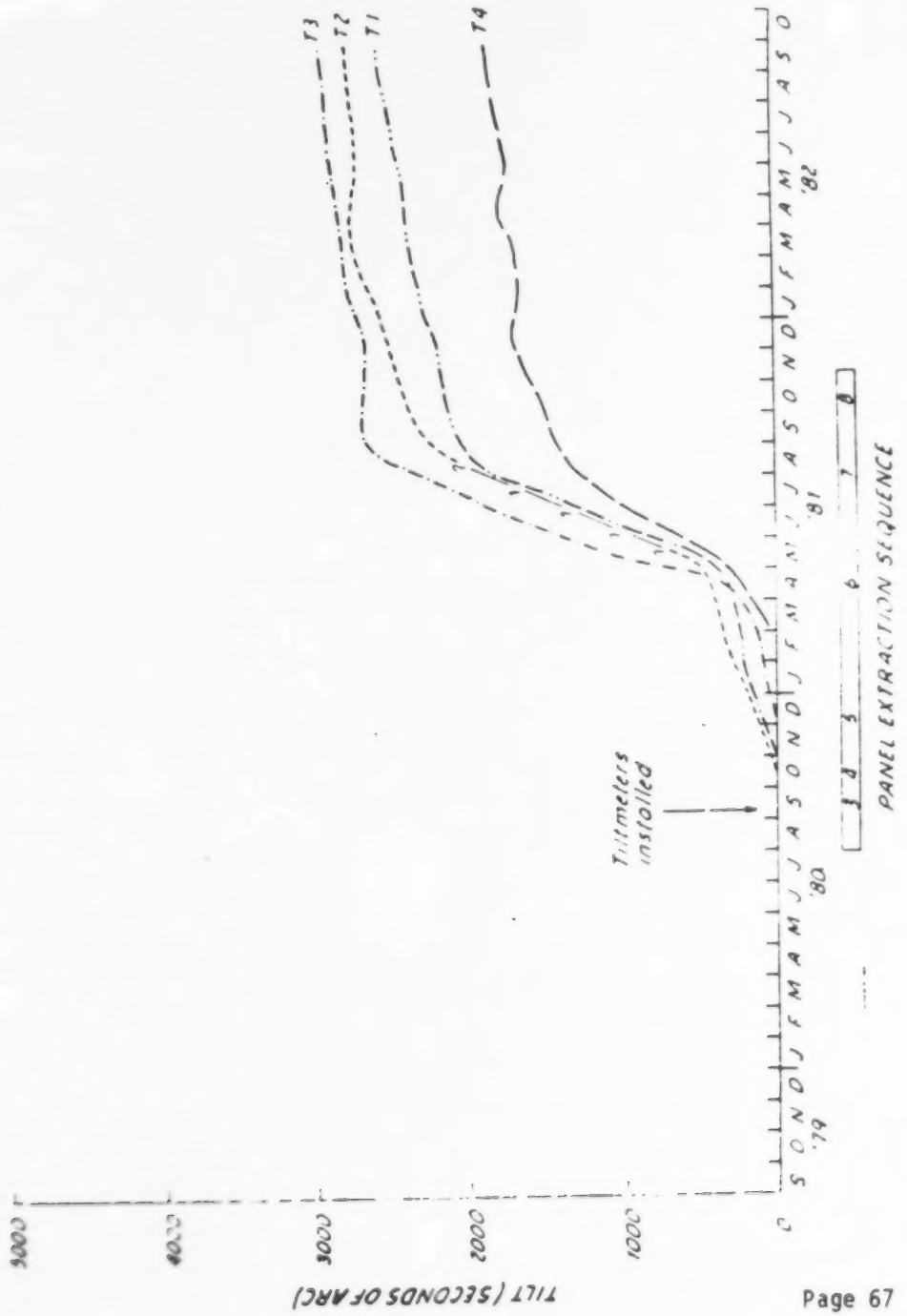
LEGEND

- ☆ Aerial photogrammetry
- ● Laser target
- ○ Tilt station

Note From information supplied in draft by Canmet
For illustrative purposes only

FIGURE 43

PANEL 6100 TILTMETER MEASUREMENTS



changes in response, was not considered worthwhile because the ground surveys did not occur regularly and did not provide good coverage during the first 4 months of 1981, when significant ground subsidence seems to have started to occur. In addition, the tiltmeters were relatively closely spaced near the top of the slope. It is reasonable to expect that these tiltmeters would not experience any significant surface movement until the "front" of surface subsidence, which would tend to progress up the slope as extraction proceeded, reached them. In this respect, it is significant that ground targets B3 and B4, which Westar managed to survey in February and March 1981, already showed significant vertical displacement (see Figure 40). These targets were located on the lower slopes where one would expect subsidence activity to be initiated. Results of ground surveys of targets along line 1 (see Figure 42) also appear to confirm this hypothesis.

3.2.5 (iv) Aerial photogrammetry - comparison of sequential photographs to determine movement;

The available data indicated that in general, between 1 and 2m of vertical subsidence occurred over most of the extraction area. Comparison with the subsidence contours obtained for the 1980 to 1981 period indicated a limited area showing an apparent anomalous increase in elevation of 0.2 to 0.4m between 1981 and 1982. This anomaly is attributed to such factors as variable timing of flights, which resulted in non-uniform shadow patterns. However, the results for 1980 to 1981 and 1980 to 1982 based on photogrammetric comparisons were similar. The latter results mainly showed a trend for the subsidence to become more uniform over the panel area with time.

Figure 42 shows the comparison along a typical profile between ground surface movements measured by geodetic ground survey and by photogrammetric analysis. The results obtained by both methods compare very favourably.

3.3 SUBSIDENCE REQUIREMENTS

3.3.1 Regulatory Requirements

Although there is nothing specific relating to ground monitoring requirements in the coal mines act and regulations, it is a requirement to submit a work system plan for approval by the provincial mines inspector and is referred to in the Mines Act, Chapter 28, Part I, Section 6, Paragraph 5(a), and reads as follows:

The plan of the system shall:

a) be prepared taking into consideration the safety of the public and persons involved in the work.

The inspector's interpretation of this section of the Act in an underground environment is that the safety of the public refers to

a potential hazard such as slope instability. The safety of persons involved in the work is of course self explanatory and the plan must include items such as roof control, ventilation, method of extraction, transportation etc.

In Westar's efforts to gain approval by the inspectors as mentioned later, this section of the act was being addressed.

3.3.2 Corporate Requirements:

The corporate philosophy on matters relating to safety and compliance with the Coal Mines Act and Regulations is one of conscientious interpretation. In short, Westar Mining wishes to be, and perceived to be a responsible body in the community. It wishes to set a good example for its employees and other companies to follow.

Westar has always been a responsible operator of coal mines, encouraging its staff to work closely with government regulatory and research bodies. For example, in the environmental field, Westar set up, in the early 1970s, a large environmental group to study reclamation and ecological aspects of surface mining at elevations up to 2,200 metres in the Rocky Mountains. A nursery was established, various types of trees were grown in greenhouses using accelerated growing cycles and fertilizers. In effect, the company set the pattern for reclamation standards and procedures which were accepted by the B.C. Department of Mines.

In the case of this subsidence program, the main requirements are considered to be:

- The establishment of an efficient program to develop information to better understand the strata movement above the steep thick seams.
- The joint participation with Canmet in the preparation, execution and interpretation of results.
- The acceptance of adequately safe and efficient procedures during this program.

In matters relating to production, efficiency and costs, the corporate requirements were naturally aimed at promoting and supporting improvements. At the beginning of the program, the accent on economic aspects was not so great as in more recent years. Earlier, some longer term research and development was undertaken with little more than a hope of achieving improvement. Today a request for funding has to spell out the quantifiable advantages which are to be expected from the research project.

3.3.3 Expected Subsidence Hazard:

The main hazard associated with subsidence, especially in terrains such as on Westar's property, is one of slope instability and

formation of large cavities as photographed on the surface above Panel 4. Measurements taken during the study indicated that the horizontal displacement in some areas was of the same magnitude as the vertical displacement. This phenomenon, especially in mountainous regions can cause stability problems and prompted the company to contract Golder & Associates to investigate the area of concern.

3.4 COMPANY PARTICIPATION

3.4.1 Corporate Objective:

Westar's initial objectives in participating in this joint project were to:

a) Improve safety of the men working underground.
b) Understand and predict the overall ground movement in order to assist in mine planning and operating efficiency improvement.

The intent was to later apply a good business approach in continuing with the program related to the following:

c) High speed drivage of entries to improve entry support and strate control.
d) Improvement in the recovery of coal.
e) Improvement in productivity (See Section 3.5.2)

3.4.2 Corporate Involvement & Commitment

Although there were a number of staff changes during the program, Westar continued to play an active part. As mentioned in Section 2.5, the project organization as shown on Figure 44 outlines the participation of senior management. In addition to the organization at an operating level, the project was taken to the Board of Kaiser Resources (Westar Mining) and strongly supported by the Vice President, later President, Walter Riva, an eminently experienced underground coal mining engineer.

The company's commitment to the program during the 8 years was estimated to be approximately $350,000 as outlined on Table 4. It is estimated that Canmet's costs would by 1-1/2 to 2 times this amount.

The corporate involvement in the preparation of the program was not large. The program design was delegated to the mine staff responsible for the operations and engineering, especially the manager of engineering and the mine manager. At the time, there were no severe curbs on funding such projects. Today a request for funding would have to be accompanied by an economic assessment of the payoff to be expected and what the chances of achieving the expected results would be.

If Canmet had not approached Westar to participate in this program, the author is of the opinion that Westar would not have initiated the research by itself or in conjunction with another research agency.

3.4.3 Impact of Measurements on Mine Operations, Development & Planning

Although the program was initially research oriented rather than of a practical nature, the operating personnel realized that the outcome of the data collected could be applied in future developments or planning of new underground mines within the area. Although all the information was not available for the Panel 6 mine, benefits that could be derived from the program included:

Underground:

1. Layout of Mine
2. Sequence of Extraction
3. Pillar Sizes
4. Junction Design
5. Size of Roadway
6. Type of Roadway Support
7. Initiation and Propagation of Caving Front

Surface:

1. Strata Behavior
2. Breakline to Surface
3. Slope Stability

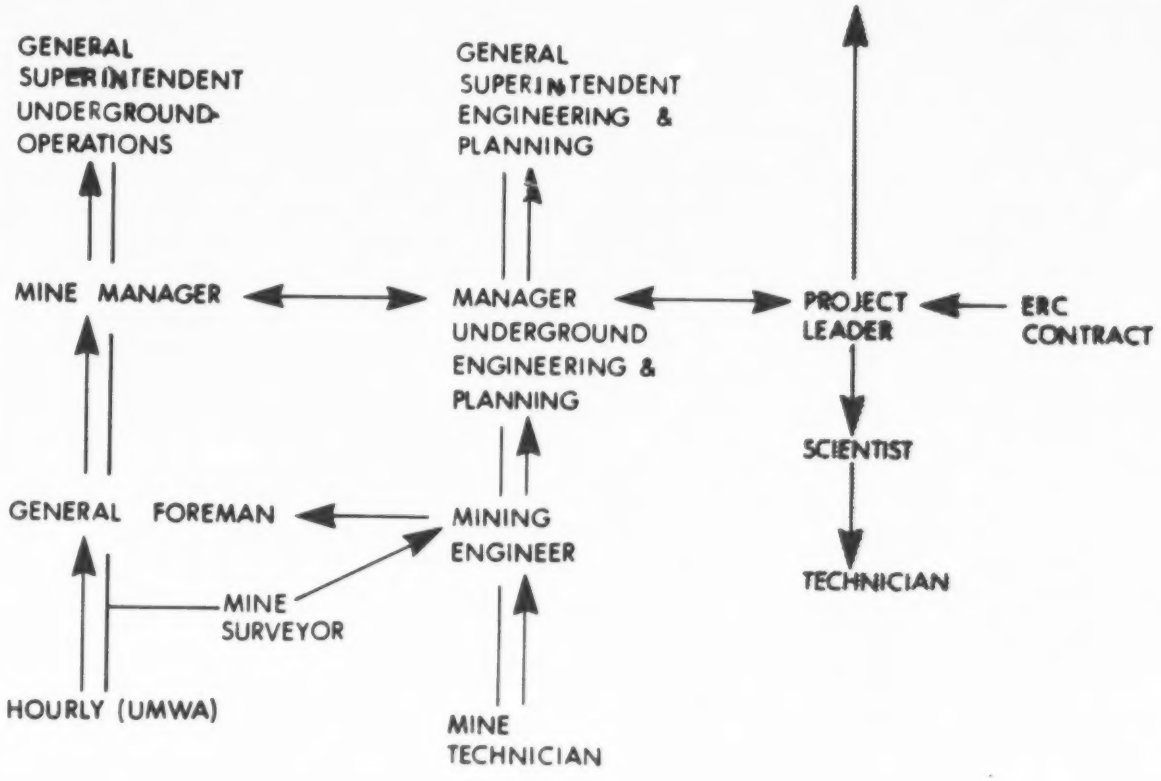
In 1983 the underground planning group had estimated that the reserves in Panel 6 would be exhausted by 1989. Consequently an application was submitted for a replacement mine namely Baldy 10. The mining system proposed for this new mine included the items listed above and approval from the Provincial Department of Energy Mines and Petroleum Resources based on this system was granted. More specific aspects are covered in the section on usefulness to other mines, Section 3.5.2.

3.5 BENEFITS OF MEASUREMENT

3.5.1 Validity Considerations

After the air blast at 20 sub level in February 1983 in 6100 Panel, both CANMET and Westar reacted to the problem and demonstrated that some expertise gained over the years could be implemented. Before continuing extraction in 6100 Panel, and before initiating extraction in 6200 Panel, a suitable monitoring strategy had to be established and presented to EMR for its approval.

The monitoring program submitted for approval was designed to verify that caving is progressing in a gradual and controlled



Westar Engineering

PROJECT ORGANIZATION

SUBSIDENCE STUDY

FIGURE 44

manner as confirmed by E.D.M. measurements as the primary source of data, with aerial photogrammetry being used for supplementary or backup measurements.

E.D.M. measurements in 6100 Panel were taken on a weekly basis utilizing 19 targets. Over Panel 6200, 31 targets were installed and again readings of both vertical and horizontal displacement were recorded weekly. The frequency of measurements was then extended to two weeks after it had been established that subsidence was taking place.

This information was then recorded and all readings tabulated as shown on Table 2 & 3.

3.5.2 Usefulness To This Mine, The Canadian Mining Industry

During the subsurface measurement phase, the support load of the arches revealed that yielding took place at approximately 50% of design in sub levels and only 25% in main entries. This established that the bolt clamps on these arches had to be re-torqued. It is apparent from this program and other experience that yielding arches have to be retorqued on a regular basis by following a specific schedule.

Further measurements revealed that there was no significant pillar load in the area close to the working face, but on the other hand the data suggested that the area of influence tends to be greatest 150-300 meters ahead of the face, but even here the abutment pressures are not great.

During the coal extraction operation of Panel 6200, this area of influence of abutment pressure, see Figure 32, did in fact occur at between 150-300 meters ahead of the working face. In addition, in some areas, the length of this abuttment pressure influence was approximately equal to the depth of cover. In the main entries additional supports were required and in the producing sub levels productivity increased by 4 - 6 times due to fractured coal.

The information generated in this program will be useful to both Westar in any future mines and for other mining companies, geotechnical engineers and research organizations. In our opinion, the characteristics observed are not peculiar to the type of mining, but are also applicable in any steeply dipping seams in the Rocky Mountains (and probably in other geological formations). As this method of hydraulic mining is a form of room and pillar mining applied to steeper (and in this case thicker seams), jet cutting is used for pillar extraction instead of continuous miners or drill and blast. Of considerable interest is the percentage of coal recovery, which in conventional room and pillar operations may be low enough to prevent the full caving of the goaf and hence transfer of the stress into the worked out area, resulting in considerable front abutment pressure on the pillars awaiting to be extracted. Figures of percentage of coal recovered were kept and provide the source data for an interesting additional study.

It was disappointing that no comments of the pillar size was made in the project report and that no firm recommendations were made regarding future mine design from a geotechnical point of view.

3.5.3 Impact of techniques on Future Mines

During the research program the contract with E.R.C. was initiated to install a tiltmeter system with computerized radio-telemetry. The system was designed, constructed, tested, and improved as digital technology advanced. The system installed over Panel 6 consisted of a master station and 5 slaves.

The development of this system however was regarded as a prototype, because cost considerations meant that too few slaves were used in accurately measuring the whole subsided area. It is Westar's understanding that this original system has now been further developed and is presently being applied for slope stability and tailing dam wall movement in the oil sands surface mining applications.

Parameters for future underground monitoring programs can be considered by optimizing the following factors:

a) Meaningful parameter(s) which are indicative of surface subsidence activity should be measured.

b) Measurements of parameters should be made at a representative number of locations above the mining area, with recorded points 50 to 200 metres apart, depending on the primary purpose of the measurements.

c) Frequency of measurement should be compatible with the anticipated rate of occurrence of subsidence.

d) Method should be reliable on a year-round basis.

e) Results should be obtained sufficiently quickly so that an appropriate response by mine staff to anomalous behaviour is possible.

f) Accuracy of measurements should be such that meaningful and important trends in surface subsidence are actually detected.

g) The method should be capable of being carried out at reasonable cost with minimal inconvenience to mining operations or engineering staff.

To induce a caving front as quickly as possible in Panel 6200, the outcrop pillar was reduced from 50 meters to 25 meters to ensure that the bridging effect of the main roof was minimized and replaced as far as possible by a cantilever effect. The E.D.M. measurements over this Panel did demonstrate a definite relationship between underground activity and surface deformation. The existance of such a relationship is not necessarily a guarantee that

hang-ups and subsequent large roof falls will not occur. However, the occurrence of substantial and progressive surface deformation did demonstrate that the full thickness of the rock mass was deforming.

TABLE 2

SUBSIDENCE MEASUREMENTS OVER 6100 PANEL

OBSERVATION PERIOD JULY 13 - JULY 20

[illegible]	INSTALLATION DATE	BASE CO-ORDINATES (FT)			MOVEMENT DURING OBSERVATION PERIOD (FT)			TOTAL MOVEMENT SINCE TARGET INSTALLATION		
		LAT.	DEP.	ELEV.	LAT.	DEP.	ELEV.	LAT.	DEP.	ELEV.
1	MAY 4/53	N 601.9	W [illegible]	[illegible]	0	0	-0.2	S 0.9	W 1.0	- 2.1
2	"	N 928.2	W 3277.0	5540.8	S 0.1	0	-0.1	S 1.0	W 1.8	- 1.9
3	"	N 532.4	W 3269.1	5540.8	S 0.1	0	-0.3	S 0.6	W 2.1	- 2.4
4	"	N 339.6	W 3271.5	5582.9	S 0.2	W 0.1	-0.2	S 0.8	W 1.8	- 2.4
5	"	N 155.4	W 2582.8	5616.1	S 0.1	W 0.3	-0.3	S 0.3	W 1.0	- 0.9
6	"	S 200.3	W 2580.6	5536.1	0	W 0.3	-0.1	S 0.3	W 0.7	- 0.6
7	MAY 12/53	N 6.9.2	W 2575.1	5613.1	0	0	-0.1	S 0.3	W 0.7	- 0.9
8	MAY 11/53	N 106.5	W 2581.2	5620	0	0	0	S 0.1	W 0.2	- 0.1
9	"	N 101.2	W 2584.4	5570.4	S 0.1	W 0.3	-0.3	S 0.5	W 0.8	- 0.9
10	"	S 195.7	W 2586.0	5540.5	S 0.1	W 0.1	-0.2	S 0.2	W 0.3	- 0.6
11	"	S 390.9	W 2586.1	5568.4	0	W 0.1	-0.1	S 0.1	W 0.1	- 0.2
12	MAY 10/53	N 1019.1	W 3252.1	5674.2	0	W 0.1	0	S 0.3	W 0.6	- 0.9
25	JULY 13/53	S 478.7	W 2596.6	5582.5	0	W 0.1	-0.1	0	W 0.1	- 0.1
26	"	N 27.6	W 2637.9	5598.0	S 0.2	W 0.2	-0.2	S 0.2	W 0.2	- 0.2

TABLE 2

SUBSIDENCE MEASUREMENTS OVER PANEL 6

OBSERVATION PERIOD FROM : 84/OCTOBER 28 TO : 84/NOVEMBER 5

STATION #	INSTAL. DATE	CO-ORDINATES OF BASE (FEET) LAT.	DEP.	ELEV.	MOVEMENTS DURING OBSERVATION PERIOD (FEET) LAT.	DEP.	ELEV.	TOTAL MOVEMENT (FEET) (SINCE TARGET INSTALLATION) LAT.	DEP.	ELEV.
15	83/SEP [illegible]	S1991.2	S1929.3	5010.2	0.	0.	0.	1.1	0.5	0.1
17	83/SEP [illegible]	S4671.3	S1790.6	5101.3	0.1	-0.1	-0.5	0.8	-2.3	-4.0
20	83/SEP 29	S4770.8	S1674.9	5131.2	0.2	0.1	-0.1	1.4	0.6	0.1
21	83/SEP 29	S4735.8	S1518.0	5165.0	0.1	-0.3	-0.2	-0.0	-1.5	-1.0
27	83/SEP 29	S4542.2	S1270.6	5373.4	0.1	-0.7	-0.6	-0.0	-2.3	-2.0
28	83/SEP 29	S4022.6	S1235.2	5452.5	0.2	0.9	-0.9	0.1	-3.2	-3.0
29	83/SEP 29	S3944.2	S1278.6	5576.8	-0.1	-0.1	-0.1	0.8	-0.7	-1.0
33	83/SEP 29	S3956.1	S1213.2	5414.2	0.2	0.1	-0.1	1.4	0.6	-0.0
34	83/SEP 29	S4558.1	S 297.7	5497.2	0.0	-0.3	-0.2	-0.2	-0.7	-0.6
35	83/SEP 29	S4175.3	S 917.8	5693.1	-0.1	-1.0	-0.8	0.5	-3.3	-2.6
36	83/SEP 29	S3717.8	S 902.3	5628.4	0.0	-0.4	-0.3	-0.0	-0.9	-0.7
37	83/SEP 29	S3102.7	S 966.2	5809.4	0.0	-0.1	-0.0	0.0	-0.2	-0.5
38	83/SEP 29	S2732.9	S1225.8	6052.7	0.2	0.0	-0.2	0.1	-0.2	-0.3
39	83/SEP 29	S3160.8	S1454.4	5747.2	0.0	-0.2	-0.1	-0.5	-0.6	-0.8
41	84/OCT 02	S5080.1	S2297.7	4905.0	0.1	0.0	0.0	0.1	0.0	0.0
42	84/OCT 02	S5229.1	S2449.9	4930.9	0.1	0.1	-0.0	0.2	0.0	0.0
43	84/OCT 02	S5106.4	S1956.6	5105.2	0.1	0.1	0.0	0.2	0.1	0.0
44	84/OCT 02	S4752.1	S1267.5	5262.0	0.1	-0.3	0.0	0.1	-0.2	-0.1
45	84/OCT 02	S4550.3	S1043.6	5443.0	0.1	-0.7	-0.5	0.2	-0.6	-0.5

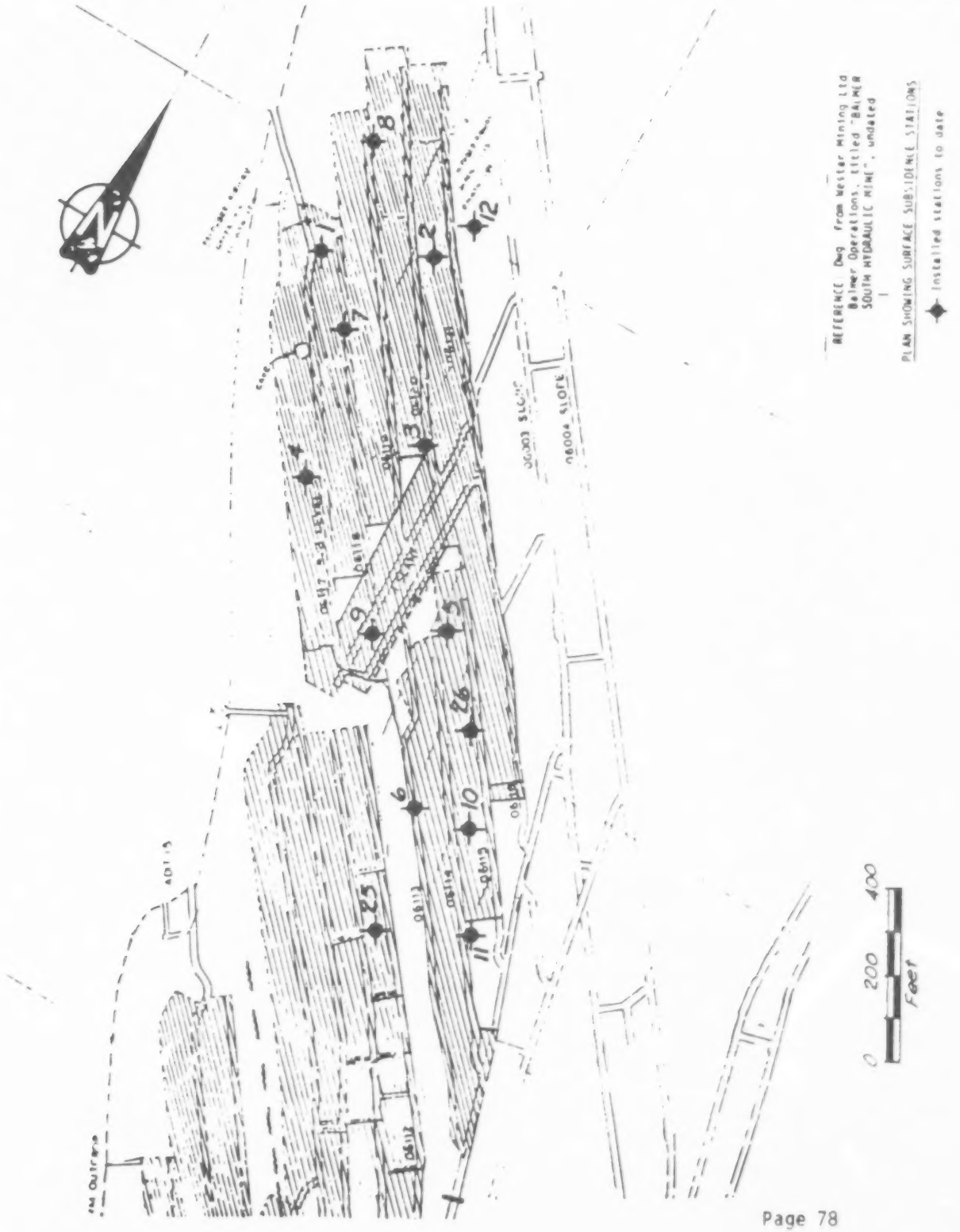
TABLE 3

NEGATIVE LATITUDE MEANS SOUTH, EXAMPLE : -0.1 IS S 0.1

NEGATIVE DEPARTURE MEANS WEST, EXAMPLE: 0.2 IS W 0.2

BALMER SOUTH MINE - SUBSIDENCE TARGETS
PANEL 6100 - SUBS 13-21

Figure 3



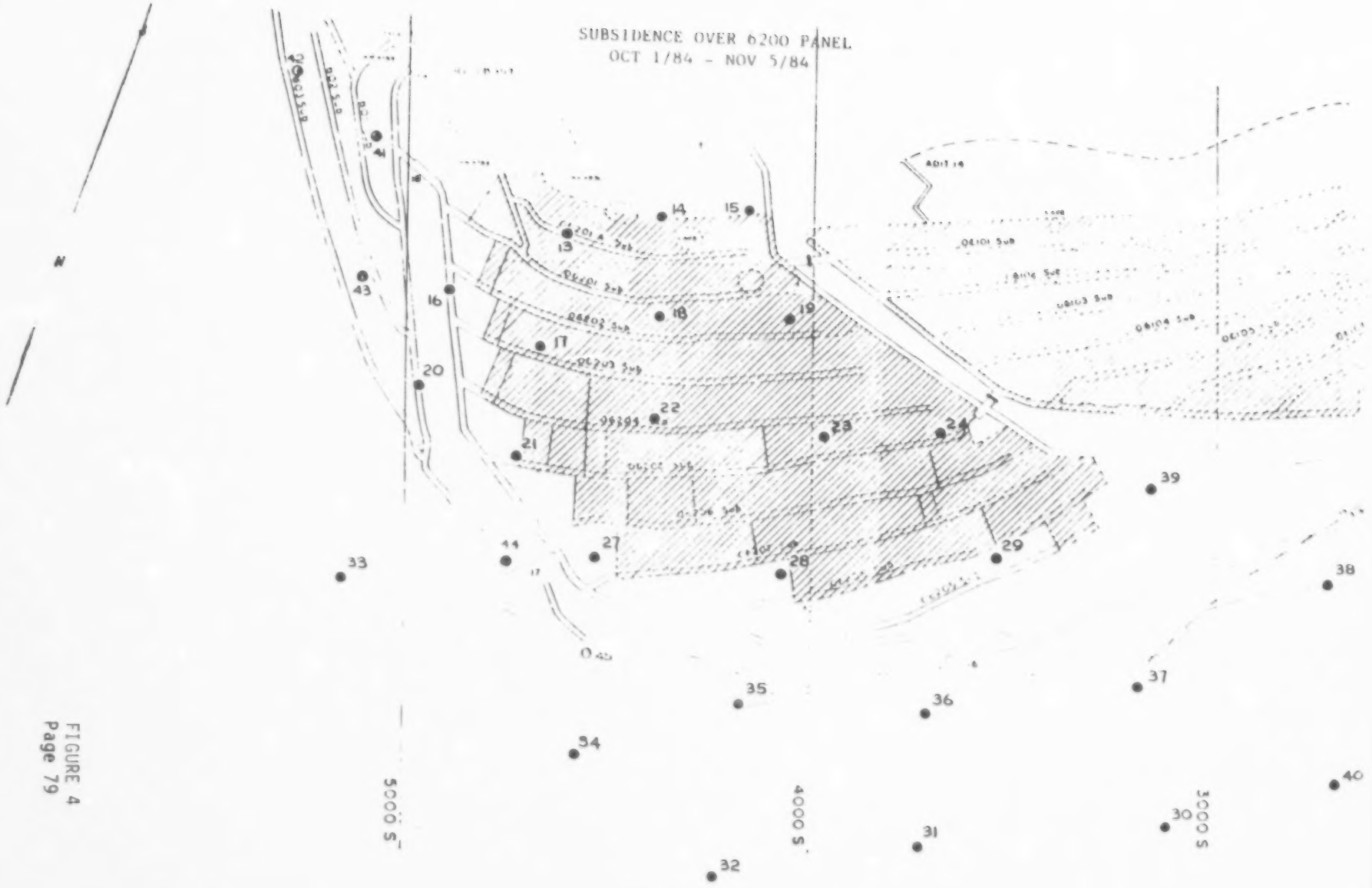


FIGURE 4
Page 79

TABLE 4

WESTAR'S COSTS INCURRED DURING PROGRAM

YEAR	CAPITAL	OPERATING	INSTALLATION
1975	$9,218	$2,365	
1976	$10,051	$2,750	
1977	$1,937	$4,427	
1978	$5,000	$10,000	$24,000
1979	$23,000	$35,000	$27,000
1980		$34,000	$29,000
1981		$35,000	$29,000
1982	$6,000	$34,000	$28,000
TOTALS	$55,206	$157,542	$137,000

GRAND TOTAL $349,748

N.B. YEARS 1975, 1976 AND 1977 ARE ACTUAL
YEARS 1978 TO 1982 ARE ESTIMATED

SECTION 4.0

CONCLUSIONS

The program was initiated under the direction of Jim Anderson, Mine Manager who reported to Arthur Grimley, General Superintendant of underground operations. During the 8 years of the program a number of changes took place at senior management levels; in addition, both CANMET and Westar lost some key people who were actively involved in this research project.

The initial objectives of the program were not really clearly defined and appeared to be of a theoretical nature; the development of instrumentation was a major item. Consequently the operating people became less enthused with the program. However, as time progressed the usefulness of the program became apparent; consequently the enthusiasism returned and accounted for the favourable response in dealing with the situation subsequent to the air blast.

The relationship between rock mass deformations and underground extraction did result in surface deformation on the slopes and it established within reason the rate of deformation versus time for some areas at various depths of cover up to approximately 300 meters.

this relationship could have been analysed before the final report was written or during the research program. However one of the major concerns from an operating point of view is that during the research program CANMET or E.R.C. should have had a man full time at the mine site. This would have speeded up the response time in relation to data interpretation because moving the measurements to Calgary and receiving the data back from there was a rather slow process.

Unfortunately, 6200 Panel was closed just prior to working an area with cover in the order of 500 meteres. This area is north of the fault shown on the plan attached to Table 2. Westar's requirement at that time was related to the provision of firm evidence of the continuation of the caving front whilst working the new block at that depth of cover; deformation on the surface might not take place. Consequently the underground engineering staff started to investigate the possibility of conducting measurements underground by various methods. It was important to prove that the roof was eaving, rather than hanging up. However, due to the mine closure, these investigations were never completed.

Generally speaking the 8 year program did accomplish reliable methods for surface subsidence measurement. However, the approach to predicting subsidence with respect to proposed mine layout from all data collected during this program is not considered complete. Also, the approach did not meet several of the main objectives, which are reproduced in the Appendix I.

Further work is required on the effects of a major fault and interruptions of coal extraction on the subsidence measurements. In addition, percentage of coal recovery should have been included during the study because this would have had a significant correlation to the extent of surface deformation and strata behaviour.

APPENDIX I

1. 1978 - Ground Control Program & Objectives

1.1 Program:

i) Installation of 3 ground control stations.
ii) Weekly monitoring of existing stations.
iii) Preparation for 3 ground control and 5 strata hole stations.
iv) Completion of the surface subsidence monitoring network over sub-panel 06001.
v) Trial monitoring of surface subsidence network during the winter months.

1.2 Objectives:

i) Analysis of ground movement in relation to mine extraction.
ii) Initial analysis of ground movement in relation to high speed mine development.
iii) Analysis of ground movement in relation to conventional development i.e. continuous miners.

2. 1979 - Ground Control Program & Objectives

2.1 Program:

i) Installation of 5 ground control stations.
ii) Installation of 5 outcrop pillar bolt stations.
iii) Installation of 2 strata hole stations.
iv) Weekly monitoring of existing stations.
v) New development investigation of methods for future related research work.
vi) Trial monitoring of surface subsidence network during winter months.

2.2 Objectives:

i) Analysis of ground movements in relation to mine extraction/development of existing ground control stations.
ii) Analysis of barrier pillar movement in relation to mine extraction/development from existing outcrop pillar hole and strata hole stations.
iii) Evaluation of high speed mix development in relation to ground movement and pressures.
iv) Evaluation of ground support systems.
v) Analysis of ground pressures on junction support systems.
vi) Initial evaluation of junction support designs.
vii) Evaluation of new ground monitoring systems.

3.0 1980 - Ground Control Program and Objectives

3.1 Program:

i) Installation of 5 ground control stations.
ii) Installation of 3 strata bolt stations.

iii) Expansion of surface subsidence network.
iv) Weekly monitoring of underground and surface stations.
v) Field trials of new ground monitoring techniques.

3.2 Objectives:

i) Analysis of barrier pillar movement in relation to mine extraction/development from existing outcrop pillar hole and strata hole stations.
ii) Analysis of surface subsidence movement in relation to ground and barrier pillar movement and mine extraction.
iii) Evaluation of new ground monitoring techniques.

4.0 1981 - Ground Control Program and Objectives

4.1 Program:

i) Installation of 2 ground control and 2 strata hole stations.
ii) Field installation of new ground monitoring system.
iii) Installation of surface subsidence monitor network over subpanel 06002.

4.2 Objectives:

i) Analysis of ground, barrier pillar and surface movements (as for previous years).
ii) Analysis of data obtained from the new ground monitoring system.

5.0 1982 - Ground Control Program & Objectives

5.1 Program:

i) Installation of 2 ground control stations.
ii) Field installations of new ground monitoring system.
iii) Expansion of surface subsidence network over subpanel 06002.

5.2 Objectives:

i) Analysis of ground, barrier pillar and surface movements (as for previous years).
ii) Development of a mathematical models to determine optimum barrier pillar size, for various conditions (i.e. depth of cover), for hydraulic mining operations in thick, steeply dipping coal seams.
iii) Development of mathematical models to predict the ground and barrier pillar movement, ground pressure and surface subsidence in relation to hydraulic mining operations in thick, steeply dipping coal seams.
iv) Design guidelines for the layout of extraction panels, coal pillars and sequence of extraction.